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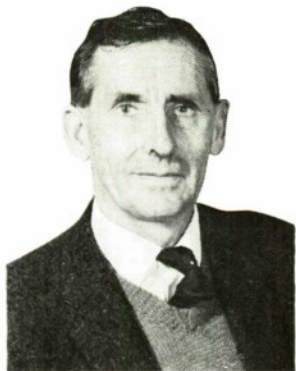
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LESSONS FROM THE S.S. "MACTRA" EXPLOSION ENQUIRY

R. G. H. Clutton, D.F.H., M.I.E.E., R.N.S.S.
Admiralty Oil Laboratory



Rex G. H. Clutton joined the Assistant Superintendent of Degaussing in 1940 from industry where he had been Works Manager of the Siemens-Schuckert (GB) factories. In 1946 was assimilated as an SSO, joining TEE Greenock as Works Manager.

Promoted to PSO in 1951 and transferred to DRPP Admiralty to head a section responsible for providing works, machinery and equipment for the Navy R & D Establishments and advice on utilisation. Joined AOL Cobham 1970, now head of Engineering. Active in Sailing, Skiing and Motor Racing. Founder member and Vice Commodore of the Civil Service Sailing Association and member of the RNSA since 1949.

Director General Ships is vitally concerned with the hazards that can exist in dealing with hydrocarbon fuels and lubricants on board Naval and Fleet Auxiliary Ships.

Admiralty Oil Laboratory has provided a background of expertise in this area, and is currently carrying out programmes covering explosivity problems ranging from vapour and mist concentrations which could exist under operating conditions in ships, and sources of ignition which could be produced by any means.

For this reason AOL staff were requested to attend the public enquiry into the loss of the S.S. *Mactra* to see what lessons could be learnt from the technical witnesses called before the Court which was presided over by Sir Henry Brandon, M.C., Q.C., with assessors Professor F. Morton, O.B.E., D.S.C., Ph.D., Professor J. M. Meek, D.Eng., Captain J. L. Holmes, and T. B. Hutcheson, Esq., M.B.E. The author was only one of those members of AOL who attended the *Mactra* enquiry which, by its judicial nature, has been very long and tiresome, the evidence took from October 1971 until March 1972 to collect. Because the Court has not yet published its findings no official opinion is expressed. This article reflects information gathered by AOL staff from the Court and the study of related papers.

S.S. *Mactra* was built by Kieler Howaldtswerke and sailed on her maiden voyage in March 1969, she was employed in the Persian Gulf/Continent crude oil trade.

Her 1,070ft. length, 157ft. beam and 80ft. moulded depth made her one of the largest of the very large crude carriers or "VLCCs" at the time, at 207,000 tons summer deadweight. Her service speed of 16 knots came from 28,000 shaft horse power on a single screw. She carried her cargo in eight wing tanks and five centre tanks, with permanent ballast forward in three wing tanks and two tanks aft of the slop (oil separating) tanks, of which there was one on each side.

On Monday, December 29, 1969, on a fine day after lunch, in position 19° - 27° South and 39° - 07° East, which is between Madagascar and the mainland, and on a course 029°, her orderly progress of tank washing by "Gunclean" jets (Fig. 3) was rent by disastrous explosions in No. 4 centre tank, which lifted the whole of the deck plating, knocked down internal bulkheads and bulged the hull out 4ft. in way of No. 4 centre tank.

Hampered by fracture of the fire mains when the deck lifted, Chief Engineer Edmondson, staff and crew attacked the blaze and controlled it by 0100 on December 30, but Grade I Seaman Lincoln, recently married and due for a shore job, was missing, later found dead in No. 4 tank, and the Third Officer, who was working in a lifeboat, was missing presumed blown into the sea. Other casualties were the Second Engineer's wife, sunbathing on the monkey island and badly scorched by the radiant heat of the blast, and Petty Officer Rodwell, who was found lying on top of the lift mechanism on the bridge. Seamen Emmerston and Marfitt were also hurt on their way up a ladder from the main to the boat deck.

The Second Officer's wife, Mrs. Brodie, played an invaluable role as a trained nurse, and later the Frigates *Chichester* and *Euryalus* took charge in treating and landing the injured. The ship was eventually berthed safely at Durban under tow on January 14th.

The *Marpessa*, another Shell VLCC, had also been struck by an explosion while tank washing, and by an unfortunate series of Christmas time radio difficulties, a general call sign from Shell Centre to all crude carriers about tank venting and washing had not been received on board *Mactra* on the 24th December. Had this warning been received the disaster might have been avoided.

However, because of explosions in three VLCCs during the period 14th - 29th December 1969, operators throughout the world were gravely concerned, and the tanker industry put in hand immediate costly and far-reaching investigations to look into safety. The central correlating body was the International Chamber of Shipping Tanker Safety Sub-Committee, which met on March 5th, 1970, producing an Interim Report of May 22nd, 1970.

Attention was quickly focused on four possibilities:

- (a) Spark ignition caused by impact of a falling object in a tank.
- (b) Auto-ignition by contact of gases with hot steam coils (*Marpessa*).
- (c) Compression ignition by impact of water jets on pockets of gas.
- (d) Ignition by electrostatic charging of the tank atmosphere.

Work has been done by Shell Thornton Research Centre to establish the effect of metallic objects such as the bronze nozzles of a "gunclean" machine as used in *Mactra*, falling into a rusty tank.

The materials present in *Mactra* were stainless steel, rusty mild steel, bronze, zinc, aluminium and copper carrying a surface film of sulphide. It would have been feasible for any of these to fall on to a rusty steel surface, the tank structure being mostly unpainted.

After multiple drop tests from a tower 28 metres high on to a mild steel plate target in an explosive atmosphere using objects made of the above materials (with the exception of aluminium) and at impact energies of 6,000 ft./lbs. produced no explosions, the validity of the test was confirmed by impacting magnesium on the rusty steel plate producing an explosion every time.

In another test technique, 40 gramme missiles were fired by compressed air at targets in an explosive atmosphere with an impact velocity of 46 metres/sec.

Although visible sparking occurred in some cases there was only a single explosion in 200 attempts with the test materials above. Aluminium and magnesium caused ignition however, and aluminium caused an explosion in 20% of the firings including when the target plate was wet.

Because there is usually rapid cooling of a single spark, residence time of sparks in a pocket of inflammable gas is a significant factor, and a series of sparks such as given

off by something rotating abrasively could be hazardous since the heating effect of a train of sparks will be accumulative.

These tests did not support the theory of an explosion caused by metallic objects dropping into the tanks of *Mactra*, but they do show that the use of aluminium in any form, including paint, increases the risk of explosion in or near tanks having potentially explosive atmospheres. It is improbable that (a) was the cause.

In *Marpessa* steam coils were in use, but the desuperheated steam was limited to 195°C and from laboratory tests the minimum auto-ignition (AIT) of the crude oils carried was 230°C. On *Mactra* cold water washing was used, so the question of steam coils did not arise, thus (b) is eliminated.

Research using a rapid compression machine established the compression ignition characteristics of stoichiometric mixtures of typical crude oil gases under adiabatic compression from atmospheric pressure at various initial temperatures to pressures up to and beyond that of the cleaning water jets. Thus, at 30°C initial sea temperature as at Madagascar and 10 Kgs/cm² water pressure of the jets, the volume of a trapped gas bubble would need to be many tens of litres, which is inconceivable in the tank cleaning environment, which disposes of (c).

This leaves (d) the possibility of ignition by electrostatic charging as the most difficult to prove, and a great deal of research has been done and is continuing on simulated shore situations in the laboratory, under ship conditions in cargo tanks, in slop tanks at sea (namely those tanks in a ship into which oil contaminated washwater is returned during tank washing).

In full scale experiments there are serious problems of maintaining control of all the variables, and in planning experiments to make clear the effect of each variable.

In work done by Shell, Amsterdam, field strengths under washing conditions have been found to lie within the range +250 kV/m to -150 kV/m, which has to be considered in relation to a generally accepted dielectric breakdown strength of dry air of 3000 kV/m. It must be remembered however, that greater field strengths can exist in the vicinity of edges and projections having small radii of curvatures (a sounding rod for example). Moreover, humidity is very high inside a tank being washed and breakdown strength is lower.

In the very large centre tanks of 200,000 ton tankers (about the volume of the nave of Westminster Abbey has been quoted) under tank washing conditions and with circulating air being blown in from one end and out of a vent pipe to atmosphere at the other, there can be considerable layer effects, and there exists a possibility of rival positively and negatively charged clouds of mist and vapour billowing about in the tanks, in a way rather similar to thunderclouds in the sky, and it cannot be discounted that incendive charges could occur in locally high field strength areas associated with tank or apparatus geometry. Hazards could also be caused by the entry of a suitable electrode from outside the tank into the charged atmosphere, for example a sounding rod on the end of a polypropylene rope already charged to a high potential by being handled by a person not wearing antistatic clothes and shoes. Even a good layer of paint on the deck is sufficient to insulate a person or apparatus such as portable connections, from earth. An incendive spark could occur as a charged person approaches an open tank lip or when he makes a connection to earthed apparatus.

Great care must be taken not to ignore the incendive possibilities of sparks created by this means. Corona discharge conditions often exist between charged atmospheres in large tanks at the field strengths likely to be found during washing, and are commonly considered to be harmless which is perhaps a dangerous assumption.

Responsible world tanker operators have expended much money and effort in working out systems for the safe transport of bulk crude oil supplies, and three definite demarcations of tank atmospheres exist and have been chosen by different companies as their operating policy; they can be called Atmospheres A, B and C. Atmosphere A is one which is not controlled at all and can be either in the flammable range above the Upper Flammable Limit (UFL), *i.e.* over-rich or below the Lower Flammable Limit, *i.e.* too lean (Fig. 1 shows these limits).

Thus, tankers chosen to wash with such an Atmosphere A keep hatches permanently closed and hope to keep all sources of ignition away, and this may be simpler in the smaller vessels or those having sub divided tanks. Atmosphere B (chosen by Shell for their VLCCs) is intended to be made incapable of burning by the deliberate reduction of the

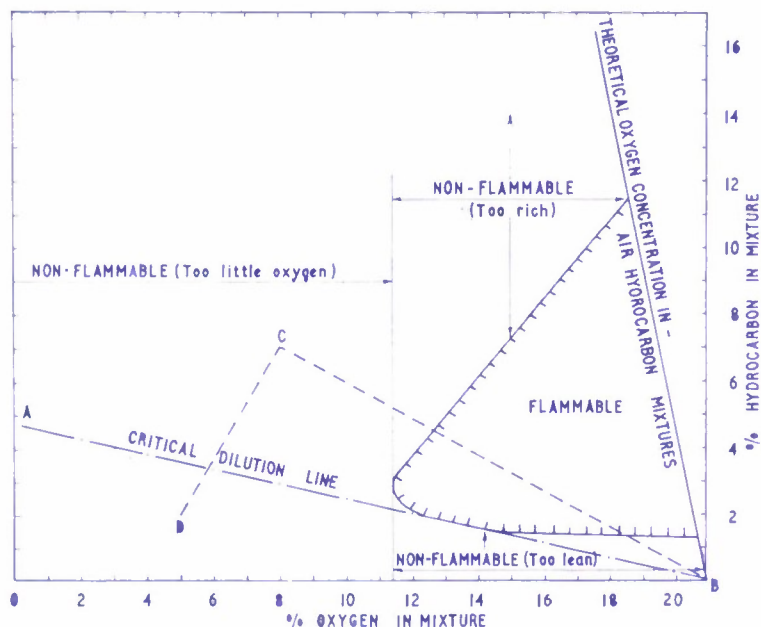


FIG. 1. Limits of flammability of hypothetical hydrocarbon nitrogen/oxygen mixtures.

hydrocarbon content to below the Lower Flammable Limit (LFL).

Tankers designed to work with Atmosphere B must have a very large air ventilating fan delivering air, usually *via* the cargo lines, to the cargo tanks in the ship to reduce the atmosphere below LFL, and venting to atmosphere *via* a stack pipe on deck about 45 cm. in diameter and over 2 metres high above its surroundings from which emerges a plume of mixed gases until the tank is quite clean.

Complex atmospheres tend to be created in large tanks since the volume increases at a greater rate than the surface area. (Tanks have gone up in recent years from 5,000 cubic metres to 34,000 cubic metres, and will probably be larger yet.) Most VLCCs have a steam turbine driven fan or blower capable of producing an air supply of about 680 m³/min. at 2,000 r.p.m. for a steam consumption of about 7 tons per hour. The equivalent electrically driven fan would require a very large power supply and supporting generating capacity.

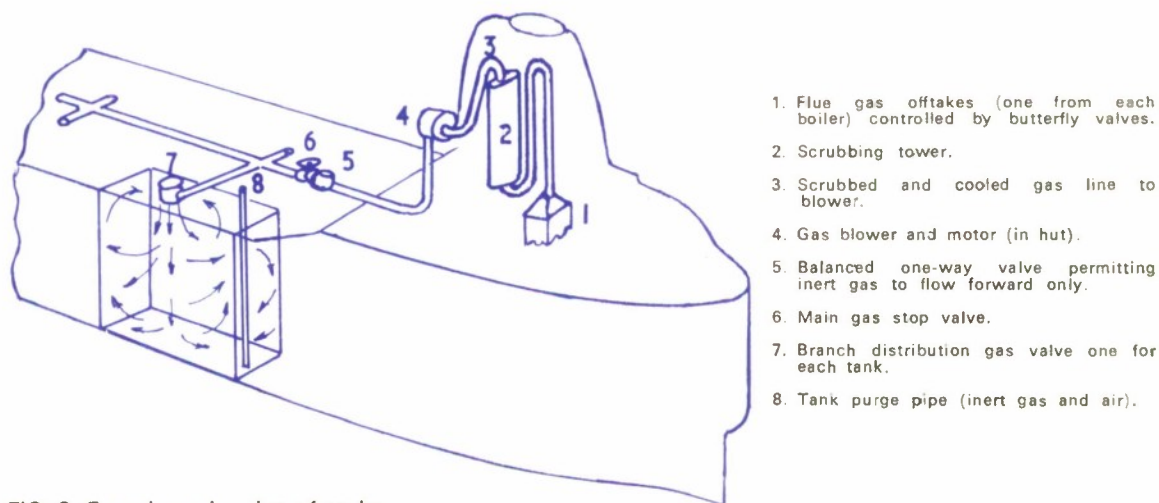


FIG. 2. Funnel gas inerting of tanks.

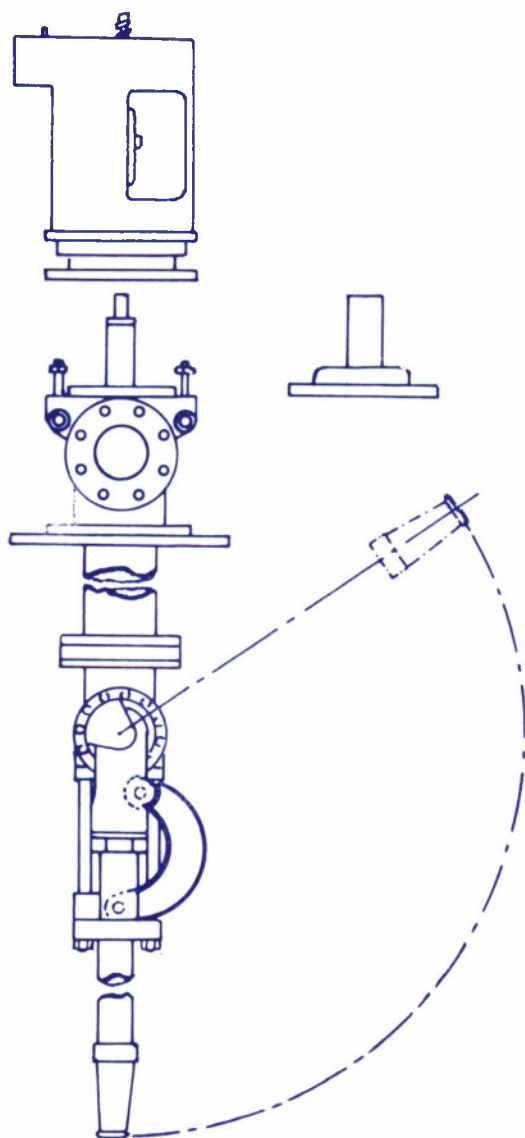


FIG. 3. "Gunclean" system of tank cleaning.

Occasionally two smaller fans can be combined for cleaning large tanks and are used singly on smaller ones, but the general principle is to provide a fresh air supply capable of reducing the hydrocarbon vapour in the largest tank to below LFL in about three hours.

Any reduction in fan speed will have a marked effect on the output of fresh air, and although in ships with a single fan it has been the practice to share the output between tanks

if atmospheres have been reduced safely below LFL, there is always a danger during tank washing in crude oil carriers that gas will be liberated by disturbing the sludge and wax. The consequent explosive atmospheres formed in a tank being washed may not be detected quickly enough for the tank washing to be slowed down or stopped and the too lean condition restored by applying the full output of the fan to this tank.

In order to be able to measure explosive atmospheres in their tankers most oil companies make use of an instrument called an MSA explosimeter, a device which sucks up a sample of gas and passes it over a heated catalytic filament which forms part of a balanced electrical circuit powered by 1.5 volt flashlight cells. Combustibles in the sample are burned on the filament which raises its temperature and increases its resistance in proportion to the combustible or flammable components in the sample. The resulting unbalance of the electrical circuit causes a deflection of a meter pointer over a scale graduated in percentage of the lower explosive limit. The sample is drawn through the system by means of an aspirator bulb which needs to be squeezed by hand five times to ensure a true sampling when used without a tube; when used in a tanker a long length of small bore hose is lowered into the tank and an extra two squeezes for each 10ft. of tube is necessary. In *Mactra* up to 75ft. of tubing was in use necessitating 20 squeezes to take a true sample.

It will be apparent that with one instrument, sampling can only take place at one position at a time in a tank, and there may be different atmosphere conditions at various depths as well as fore and aft positions in a large tank, or close to wash bulkheads which may interfere with the free passage of clean air from the ventilating fan. In the light of experience there should have been more simultaneous gas testing facilities on *Mactra*, and it is likely that more gas sampling facilities will be provided in tankers in the future as part of the fixed safety installations.

Atmosphere C. This is an atmosphere intended to be made incapable of burning by the deliberate reduction in oxygen content of the space above the cargo or washings. (Fig. 1 shows limits of flammability and it can be seen that as the oxygen content falls the range of flammability is reduced until at $11\frac{1}{2}\%$ oxygen any mixture is non-flammable.)

The simple inerting of a tank containing hydrocarbon vapour by admitting a gas such as nitrogen can be very costly if a continuous sweep of gas through the system is necessary to make up for air leaks due to contraction of the contents and other reasons.

Usually, therefore, use is made in tankers of the funnel gases, and on steamships this flue gas comes from the main boilers, while in motor ships it comes from an auxiliary boiler, and these gases are admitted to the tanks under slight positive pressure which is maintained even during tank discharging (Fig. 2 shows a typical system).

The minimum quantity of oxygen required to support the combustion of hydrocarbon gases normally found in tankers is 11% by volume. An upper limit of 8% oxygen is considered advisable by most operators and alarms are set accordingly.

Tests using this method have been conducted on VLCCs of 200,000 tons dwt to see whether all parts of the tanks were homogeneously inerted, and while hydrocarbon contents were found to be such as would have been flammable in air, the oxygen concentrations were always below that necessary for flammability.

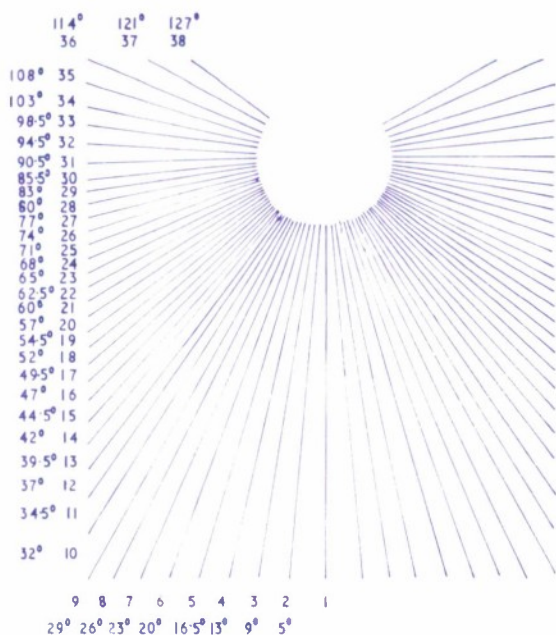


FIG. 4. "Gunclean" spray pattern. Figs. indicate number of lifting worm threads protruding above top of power unit and degrees of angle of nozzle from vertically downwards.

Some layering can take place, and the disposition of purge pipes and exits is important. There does not seem to be a rise in oxygen content during tank washing and this seems to be potentially a safe system if correctly engineered, and may well become a preferred system, with certain provisos concerning operating procedures.

Since the explosion in 1969 a great deal of practical work has been undertaken by Shell, by Universities, Consultants and others to try to establish precisely what causes tanker explosions where there has been no direct evidence of ignition, but the static discharge hazards are the most difficult to define, yet seemingly could be the most probable cause of random explosions.

A number of possibilities emerged from evidence given in the public enquiry, but no evidence appeared conclusive.

Considerable static charges are built up when tanks are washed by high pressure water jets such as "Gunclean" used in *Mactra*, and in crude oil tanks explosive gas can be liberated rapidly when sludge and wax are washed off tank walls and ledges (see Fig. 3 of "Gunclean" and Fig. 4 its spray pattern). In Fig. 5 the curve marked "Direct" shows static build up with clean sea water passing through the guns.

To avoid pollution of the sea by dirty oil washings there are usually two large oil separating tanks, one on each side of the ship. These are called slop tanks and here the very considerable quantity of sea-water used through the "Gunclean" jets and the washed residues are separated out by weirs, so that ideally only clean sea-water is re-circulated through the "Gunclean" jets to be used over and over again in the washing cycles.

It is essential to maintain strict levels in these large tanks to avoid breaking down the interfaces between separated oil and water, and it can be imagined that excessive demands for washing water might allow insufficient time for complete separation of oil and water and if this contaminated water is supplied to the "Gunclean" jets there are possibilities of a rapid rise in explosivity in the washed tank atmosphere, together with an increase in static activity arising from changes in polarity of charged droplets.

There are potential hazards either in tanks, ashore or at sea, in passing hydrocarbons and water rapidly through lines and jets, and it will be seen from Fig. 5 taken from Shell tests on a 200,000 dwt tanker that static builds

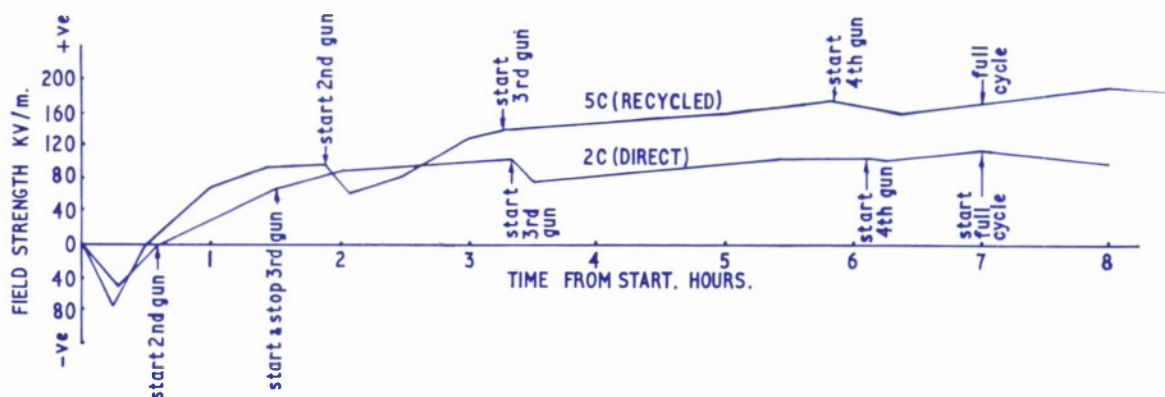


FIG. 5. Field strengths in a 200,000 ton tanker during washing.

up to a much higher value with re-cycled wash water. (Curve marked 're-cycled').

In future it will most likely be the practice to use only clean sea-water in the "Gunclean" jets, using the slop tanks for oil separation prior to disposing of the used water to the sea. This could pose pollution problems if excessive tank washing was carried out beyond the capacity of the slop tanks to separate oil and water since there is plenty of sea and only limited tank space.

Ventilating systems relying on power driven fans should always receive the designed amount of air which should not be diverted or prevented from access to a tank being processed, and in a lean system, continuous multiposition gas monitoring is essential.

In a too rich system of tanker safety air leaks should be avoided, and it may be necessary to increase the hydrocarbon content within the space by spraying crude oil, say through the "Gunclean" machines during tank emptying, and experiments have shown that field strengths are generally low when spraying crude oil. However, if low conductivity hydrocarbons such as diesel fuel were being handled, field strengths might be high.

In the absence of any known source of ignition the author considers that the *Maetra* explosion is compatible with one of the very rare incendive discharges which are thought to take place in the complex atmosphere of a very large volume tank when being washed by high pressure jets, causing ignition of a flammable pocket of gas which had not been cleared by the ventilating fan. There remains the imponderable of what poor Seaman Lincoln was doing at the actual moment of explosion when he was quite on his own by No. 4 tank lid. It is certain he had nothing more than a pair of shorts, safety shoes, possibly a small heliograph for shining the sun's rays into the tank, and a sounding rod later found in the tank. It is very unlikely he climbed into the tank where his body was found later.

Acknowledgements: Professor F. Morton, O.B.E., D.S.C., Ph.D., Shell International (Captain Jolivet, Mr. Lascelles), BP, International Chamber of Shipping, AOL Scientific Staff, Shell Thornton Research Centre.



THE DEFENCE RESEARCH INFORMATION CENTRE

R. H. Howe, A.I.Inf. Sc.



The United Kingdom has joined the increasing number of NATO countries which have set up centres with the primary function of providing documentation and information services for the national defence communities.

Introduction

In recognition of the importance of scientific and technical information, and in particular of security classified and controlled reports, to defence research and development, a special unit was set up in October 1971 as part of the Procurement Executive entitled the Defence Research Information Centre.

The staff of the new Centre, some 100 in number including 23 professional staff experienced in information science, is made up of a large element of the former Ministry of Technology Reports Centre (TRC) and the whole of the Naval Scientific and Technical Information Centre (NSTIC). Both of these organisations had, over a number of years, acquired a considerable amount of expertise in the acquisition and dissemination of scientific and technical information. The report holdings alone of the two former Centres total some 800,000 titles dating from post World War II, and these form the basic collection of DRIC. The Centre is housed in the modern office block formerly occupied by Mintech - TRC and NSTIC at St. Mary Cray, Orpington, Kent.

DRIC's Services

DRIC's services, which are available to the whole of MOD, to its R & D contractors and other associates, are centred around the acquisition, distribution and announcement of unpublished reports from UK and overseas sources. An important function is the maintenance of a master record of the classification, release conditions and distribution of MOD reports. The overall aim of the reports service is to ensure that:—

- (a) Full use is made of information which is of interest to a wider circle than that immediately and directly concerned.
- (b) The rules governing the security of military and commercial information are observed.
- (c) Documents containing private, commercial information or critical of the products of firms or other outside bodies are not released to persons outside the UK government service without prior consultation with those who might be adversely affected.

A number of ancillary services are operated including the supply of US military specifications and related documents.

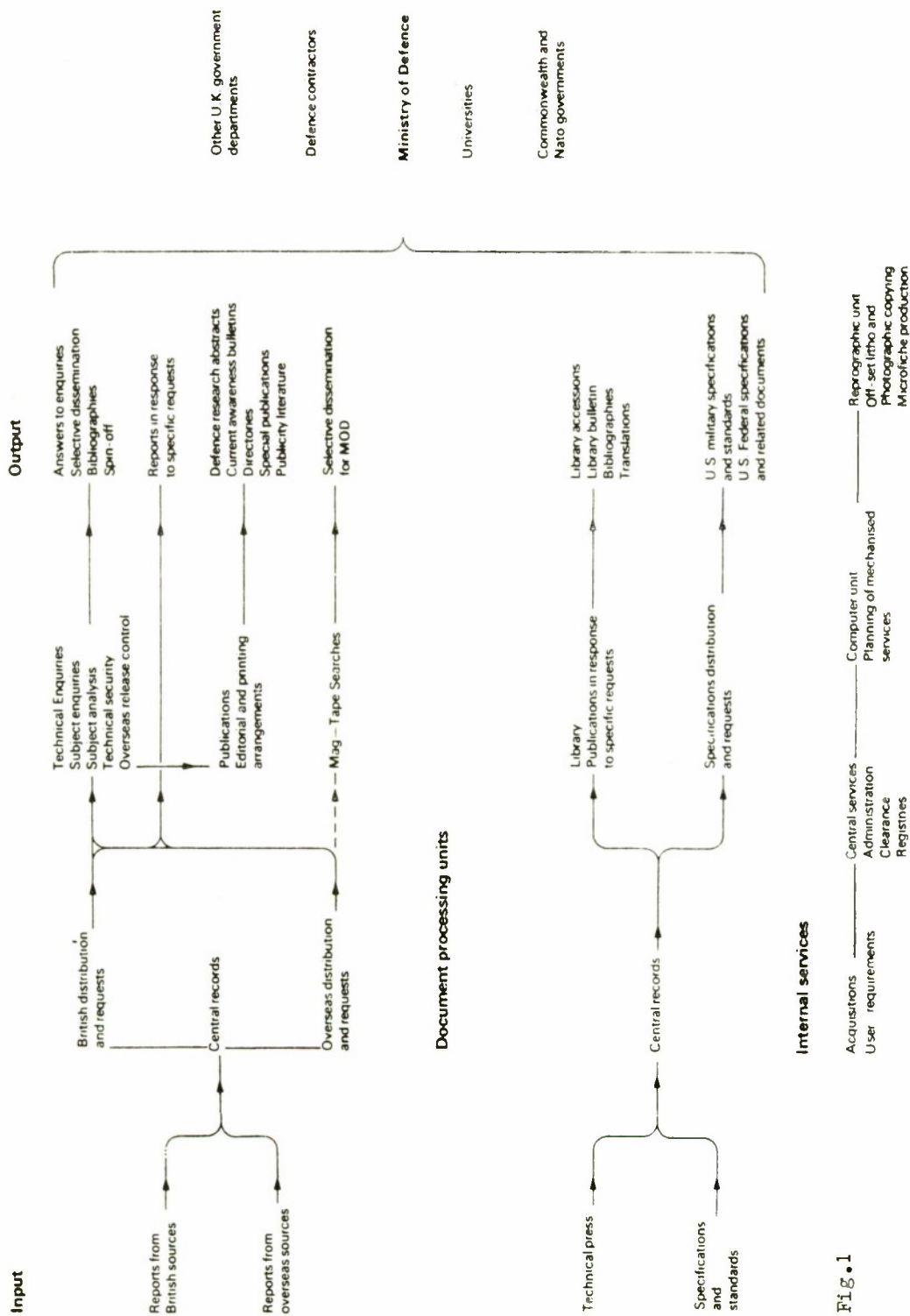


Fig. 1

DRIC continues to operate, for the benefit of the Navy Department, those services on published journals and books, translations and naval science publicity which were previously the function of NSTIC. The chart shown in Fig. 1 summarises DRIC's activities which are explained in more detail in the following paragraphs.

Scientific and Technical Reports

Acquiring Reports for the Collection

The Centre aims to obtain for permanent record, copies of all scientific and technical reports issued by MOD establishments, HQ branches and Defence contractors and also copies of reports bearing on defence R & D from other organisations in the UK and from overseas. Reports are obtained as the result of Departmental directives sponsored by DRIC (or its predecessors) requiring reports to be sent to the Centre; appropriate clauses in contracts; and from exchange arrangements with overseas defence centres. Exchange arrangements with USA and Canada are particularly fruitful. DRIC's Acquisitions Officer is constantly seeking new sources of supply of appropriate reports and the Centre will be pleased to receive copies of current reports and the opportunity to fill gaps in its collection of older reports.

Master Record Centre

The classification and Conditions of Release of British reports are checked with the appropriate Technical/Policy authorities in MOD and procedures are used to ensure that stipulated limitations on release are observed.

Clearance with Patents Branch and Release of Military Information Sections is sought as appropriate and classified and other controlled reports are transmitted to and from overseas countries *via* secure channels.

Records of all these transactions are kept at the centre.

Selective Distribution of Reports

Reports are given an initial distribution to Establishments and HQ branches against known subject interests and in 1971 about 150,000 copies of reports were issued in this way. Reports are available in paper copy and in microfiche form.

Announcement Journals

The main journal for announcing new report acquisitions is called "Defence

Research Abstracts" and is issued in two editions, designed to cater for the main groups of users:—

- (1) An edition with distribution limited to the Ministry of Defence only, issued twice monthly. This edition announces all MOD and overseas controlled reports received by DRIC, with few exceptions.
- (2) An edition for Defence contractors, also issued twice monthly. This edition announces all reports which have been approved for release to contractors.

Computer-produced indexes covering subject, author and report/accession number are included in each issue of the MOD Edition. Quarterly and annual cumulated indexes are produced as separate publications and these contain subject, author, corporate author (originator) report/accession number, conference papers, translations, contract number and title sections.

In each edition of the journal, entries are arranged under the twenty-two broad subject fields shown in Fig. 2, each field being further subdivided. The list indicates the wide subject coverage of DRIC's report collection.

Report Loan Service

Subject to the condition that "need to know" requirements must be met, all of the reports in DRIC's collection are available for loan and copies can be sent for retention if stock permits. A standard request form, DRIC/REQ/1, gives guidance to requesters on the information required to identify a particular report. The carbon copies which the four-part form automatically supplies facilitate the supply of the report from the Centre.

Technical Enquiry Service

The report collection is fully subject indexed within DRIC and in addition, the Centre holds the printed indexes of other defence documentation organisations. Drawing on all of these resources DRIC's technical staff will undertake literature searches in response to specific inquiries from the Defence community and provide an annotated list of appropriate references. Formal bibliographies on topical subjects are also issued; recent titles have been "Escape from Helicopters" and "Nuclear Hardening of Electronic Components."

1	AERONAUTICS
2	AGRICULTURE
3	ASTRONOMY AND ASTROPHYSICS
1	ATMOSPHERIC SCIENCES
6	BEHAVIORAL AND SOCIAL SCIENCES
6	BIOLOGICAL AND MEDICAL SCIENCES
7	CHEMISTRY
8	EARTH SCIENCES AND OCEANOGRAPHY
8	ELECTRONICS AND ELECTRICAL ENGINEERING
10	ENERGY CONVERSION (NON-PROPULSIVE)
11	MATERIALS
12	MATHEMATICAL SCIENCES
12	MECHANICAL, INDUSTRIAL, CIVIL, AND MARINE ENGINEERING
16	METHODS AND EQUIPMENT
16	MILITARY SCIENCES
16	MISSILE TECHNOLOGY
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12	NUCLEAR SCIENCE AND TECHNOLOGY
19	ORDNANCE
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22	PROPULSION AND FUELS
22	SPACE TECHNOLOGY

FIG. 2. Subject Fields covered by Defence Research Abstracts

As a further aid in answering enquiries, DRIC staff have access to the ESRO/ELDO Space Documentation Service mechanised information network, *via* an on-line terminal which is linked to the ESRO computer at Darmstadt.

U.S. Military Specifications

DRIC's collection of U.S. Military Specifications is probably unique in the UK. The main Milspec collection is held on 16 mm film and includes all MIL Specifications, Qualified Products Lists (QPLs), MIL Handbooks and MIL Standards.

The collection is particularly comprehensive in that all related documents cited, such as Federal Specifications and drawings are included on the microfilm and the collection is updated monthly. Some 20,000 specifications relating particularly to defence and aerospace items are also held in paper copy form. Paper copies of Milspec documents printed out from the microfilm can be supplied for loan or retention and those held in original paper copy form are also available on loan.

The staff of the Specifications Section will give advice on the location of specifications in series other than US Milspecs.

Special Services for the Navy Department

DRIC maintains several services which were previously operated by NSTIC in support of the Navy Department and the Royal Navy.

Library Services

The library is the central scientific and technical reference and lending library of the Navy Department. The more expensive scientific and technical books and periodicals are purchased for Establishments and certain HQ branches, and a loan service for books and periodicals is operated (Form DRIC/REQ/1 should be used when making requests). Subject, author and title card indexes contain details of DRIC Library holdings and also of those of many Branches and Establishments in the Navy Department.

A monthly Library Bulletin lists book accessions for the whole organisation and contains abstracts of articles of special relevance to the Navy Department from current periodicals.

Translations Service

Translations into English of scientific and technical papers from foreign journals, etc. can be provided, either by DRIC's translator

or by a panel of translators. Most languages and subject specialisations are covered. Translations on subjects of general interest are added to the input of scientific and technical reports and announced in Defence Research Abstracts, providing there are no copyright problems.

Defence "Spin-Off"

Research and development funded primarily for defence purposes often produces as a by-product to the main activity, processes, materials and devices which are not in themselves subject to any security limitations and can be utilised in the civil field. It is with utilisation of this defence "spin-off" in mind that DRIC encourages Establishments and Branches to clear suitable reports on their work for unlimited distribution. Such reports are eventually passed to the Department of Trade and Industry Technology Reports Centre for general exploitation to civil industry.

Utilisation of Microfiche

In addition to the more familiar paper copy reports, DRIC supplies an increasing number of reports in microfiche form. Microfiche are flat sheets of microfilm 148 mm \times 105 mm containing page images in several rows down the sheet. The top row carries a title strip which can be read with the unaided eye. To date a fiche format allowing up to 60 pages of text per fiche has been used for report literature but there is a growing movement for the adoption of a 98 page format. The master fiche can be used to make copy microfiche and thus a 60 or 98 page report can be copied cheaply in a single operation without time consuming printing and collation. The advantages of cheapness and speed can be passed on to the requester who receives his microfiche copy within two or three days, and for retention. Microfiche provide an economical method of storing information since up to 1000 microfiche will fit into an ordinary file drawer. Microfiche are read with the aid of a viewer, and compact, moderately priced desk-top viewers are available commercially. Reader-printers can be used to make enlarged photo-copies of all or selected pages from microfiche (see Fig. 3).

DRIC is currently developing a programme of converting all of its new report input from MOD sources to microfiche form with the

objective of facilitating distribution and long term storage. Much of the work is done using Recordak equipment installed at the Centre.



FIG. 3. Reading a Microfiche on a Reader-Printer.

Future Developments

ADP Projects

Any forward-looking technical information service must be aware of the impact of automatic data processing in the information field and consider whether any developments should be applied to its own working. DRIC has already adopted a measure of mechanisation in that records of all reports received are prepared on tape typewriters, the machine readable output being processed to give printed indexes to the Defence Research Abstract Journals and for an experimental Selective Dissemination of Information (SDI) service. SDI involves the compilation of the subject interest profile of an individual research worker or group of workers and subsequent regular computer matching of this interest profile against a data base of literature references. Matching references are notified to the customer. In DRIC's experiment, profiles from workers at two Establishments are matched against a data base consisting of references to the Centre's new report input and a purchased magnetic tape of references to US reports. Once proved the service will be extended throughout MOD.

The application of mechanised methods to "housekeeping" activities (stock control, loan procedures, need-to-know records, etc.) is also being examined.

Specialised Announcement Bulletins

As a more immediate development, the contents of the comprehensive MOD Edition of Defence Research Abstracts (DRA) are also to be made available in a series of smaller bulletins entitled DRA Digests, each covering a particular subject area. This new service will operate from January 1973 and the titles envisaged are Aerospace Engineering and Fluid Mechanics; Electronics and Communications; Materials and Processes; Military Science and Engineering; and Physics.

Unification of Documentation Procedures

Considerable attention is being paid to the unification of documentation procedures throughout MOD and DRIC has initiated or

will initiate exercises which, it is hoped, will bring clarification and uniformity in such procedures as the routine distribution of reports to overseas countries, limitation markings on reports other than security markings, regular consideration of the down-grading of classified reports and the special requirements for handling classified microfiche.

Conclusion The organisation described has been set up with the specific intention of providing a service to the UK Ministry of Defence and its Contractors. Future development will be aimed at the same goal. If you are not already making use of DRIC you are invited to do so, either *via* your local technical information officer or librarian, or if this is not possible by direct application to one of the contact points listed. If you are a Project Officer, responsible for a contract, does your contractor know of the services available?

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EXPERIMENTS ON COLLECTOR POTENTIAL DEPRESSION TRAVELLING WAVE TUBES

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Abstract

This article gives the results of experiments aimed at maximizing the efficiency of high power T.W.Ts with linear slow wave circuits by depressing the potential of the electron collector. A device for preventing noise deterioration and high current interception on the slow wave circuit, which usually accompanies the depression of the collector potential, is described. Experimental results are given and from these some approximate relationships are deduced to predict depressed collector performance.



Leonard Clough was educated at the George Spicer School, Enfield and at the Northampton Polytechnic, London, where he obtained a H.N.C. in Electrical Engineering in 1946. After a period in industry engaged in the development of cathode ray tubes he joined the R.N.S.S. in 1951 and was concerned with research and development of magnetrons, klystrons and travelling wave tubes at S.E.R.L. (Harlow) until 1969 when the Establishment was closed. At present he is engaged in work on solid state microwave devices at S.E.R.L. Baldock.

Introduction In some microwave communication or radar systems the efficiency of the transmitter is of great importance. This is especially so in the case of mobile systems where the fuel carried by the aircraft or vehicle is the only source of power. The inefficiency of the output stage can account for much of the power required to operate a high power transmitter and the heat produced by wasted power can place a further burden on the fuel supply by the necessity to pump a considerable flow of liquid coolant.

In some systems where a large instantaneous bandwidth and low noise output are required together with high gain in the final stage, a T.W.T. is the best solution for the output tube. Though the intrinsic efficiency of T.W.Ts is comparatively low, a considerable amount of power can be saved by operating the tube with the potential of the electron collector depressed below that of the slow wave circuit.

The aim of the work described in this article was to explore the extent to which the efficiency of a high power T.W.T. could be enhanced by this means and to achieve the higher efficiency with no degradation in stability or noise output.

Efficiency Enhancement by Collector Potential Depression

The Principle of Collector Depression

In T.W.Ts with low efficiency, the spread of electron velocity in the spent beam is not very large and even the slowest electrons still have a sufficient proportion of their initial energy left to enable them to reach an electrode at a potential well below the beam voltage.

Fig. 1 shows a circuit for depressed collector operation of a T.W.T. The required beam voltage V_0 is provided by two power supplies in series, but only one of these supplies (A) is required to deliver the full beam current. The collector is held at a potential V_c below that of the slow wave circuit by the power supply B which has to supply only a relatively small current.

The total power supplied is

$$P = (V_0 - V_c)I_0 + V_c(I_0 - I_c)$$

$$= V_0 I_0 \left[1 - \frac{I_c}{I_0} \frac{V_c}{V_0} \right]$$

where I_0 is the total beam current and I_c the current reaching the collector, and the efficiency is

$$\eta = \frac{\text{Output power}}{V_0 I_0 \left[1 - \frac{I_c}{I_0} \frac{V_c}{V_0} \right]} = \frac{\eta_0}{1 - \frac{I_c}{I_0} \frac{V_c}{V_0}}$$

where η_0 is the intrinsic efficiency obtained with the collector potential undepressed.

To obtain the full benefit from depressed collector working, it is important to minimize the stray current to the slow wave circuit (or any other electrode at the same potential) and thus obtain a current ratio I_c/I_0 as close as possible to unity. So long as this condition is maintained the efficiency increases as the voltage ratio V_c/V_0 is increased. However, above some value of collector potential the slowest electrons are repelled by the collector and there is a consequent reduction in the value of I_c/I_0 . A little beyond this point the current ratio falls so rapidly that the term $I_c V_c / I_0 V_0$ also reduces with further increases in V_c and the point of maximum efficiency enhancement is passed. Maximum efficiency enhancement is obtained at a collector potential which maximizes the product $V_c I_c$. This occurs when

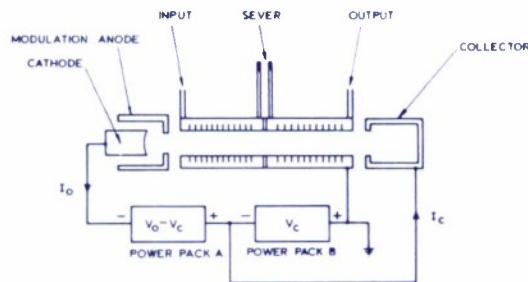


FIG. 1. Circuit for depressed collector operation.

$$\frac{d}{dV_c} (V_c I_c) = 0 \quad \text{or,} \quad \frac{dI_c}{dV_c} = - \frac{I_c}{V_c}$$

Experiments on T.W.Ts with linear (untapered) slow wave circuits show that the gradient dI_c/dV_c changes very rapidly when the collector potential depression just exceeds the value at which the slowest primary electrons are rejected and it is near this potential that maximum efficiency enhancement is obtained.

In principle, a greater saving in power is possible by the use of multi-element collectors in which a velocity sorting mechanism directs electrons to a collector at a potential appropriate for each velocity group. However it is doubtful if the extra saving is worth the added complexity of power supplies and tube construction.

Effects due to secondary electrons from the collectors

The most obvious effect that the escape of secondary electrons from a depressed potential collector will have is to reduce the collector current (I_c) and therefore impair the enhanced efficiency.

Although it may be possible to lower the secondary electron yield by suitable treatment of the collector surface (e.g. coating with a film of material having a low S.E. coefficient), it is doubtful whether such treatment would remain effective during life under conditions of intense primary electron bombardment. A more reliable method to cope with this problem is to make the collector as large as possible and to have an iris which is just large enough to avoid interception of high energy electrons. The solid angle subtended by any point on the bombarded collector surface to the iris is then very small and the small proportion of secondary electrons escaping from the collector has a negligible effect on the efficiency enhancement.

However, it has been observed⁽¹⁾ that even a small secondary electron current flowing through the slow wave circuit of a T.W.T. can cause serious deterioration in noise performance. To minimize this effect, an electron trapping electrode was devised to prevent the back streaming of electrons along the T.W.T. axis.

The Experimental T.W.T.

General Description

The T.W.T. used for the experiments was a C-band tube capable of a c.w. output of about 5 kW². Its slow wave circuit was a constant pitch, coupled-cavity, clover-leaf type with a sever midway between output and input, and operated with beam voltages from 20 kV to 30 kV. The electron gun was shielded from the magnetic focusing field and produced a beam of 3 mm diameter. A modulating anode made the beam current independent of the beam voltage thus allowing experiments over a range of beam perveance ($I_0/V_0^{3/2}$). All the experiments were conducted keeping $V_0 I_0$ constant at 28 kW and the perveance varied from 0.18 to 0.50 $\mu\text{A}/\text{V}^{3/2}$. The Pierce T.W.T. parameters C , QC and b for the experimental tubes at various beam voltages, beam currents and frequencies are given in Table 1, and Fig. 2 gives the saturated output power versus frequency.

Electron trap

The electron trap, which was held at the potential of the slow wave circuit was situated between the slow wave circuit and the electron collector. Between the inlet and the outlet irises of the trap (Fig. 3) transverse magnetic fields from a pair of bar magnets produced a transverse displacement of the primary electron trajectories. The centre of the outlet iris, and the axis of the collector were also displaced by a corresponding amount. To achieve transverse electron displacement in one direction only, components of axial magnetic field were kept to a minimum in the trap by terminating the main focusing field at the inlet iris.

Secondary electrons from the collector that enter the trap in the opposite direction to the main flow were also influenced by the magnetic field so that they were deflected further from the T.W.T. axis and were collected in the trap.

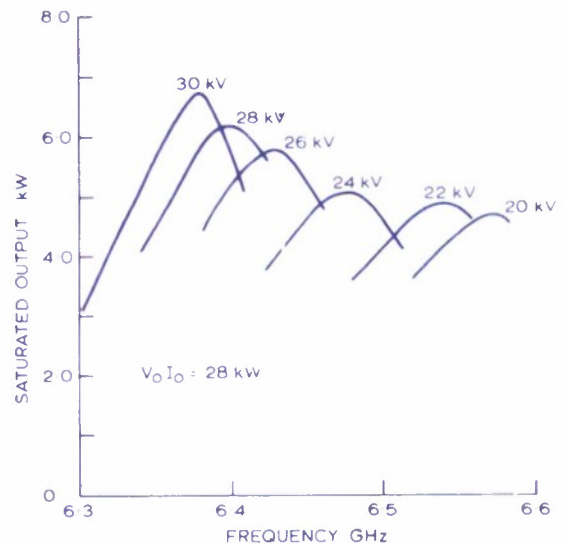


FIG. 2. Saturated output power versus frequency.

The trap was designed to have a thin vacuum wall (1 mm) between the magnets and the electron beam so that the separation between the magnets could be made as small as possible to obtain strong transverse fields. It was therefore necessary to incorporate the magnets into the electrode during construction. Barium ferrite was chosen for the magnet material because this retained its magnetic properties after the bake out temperature cycle (400°C).

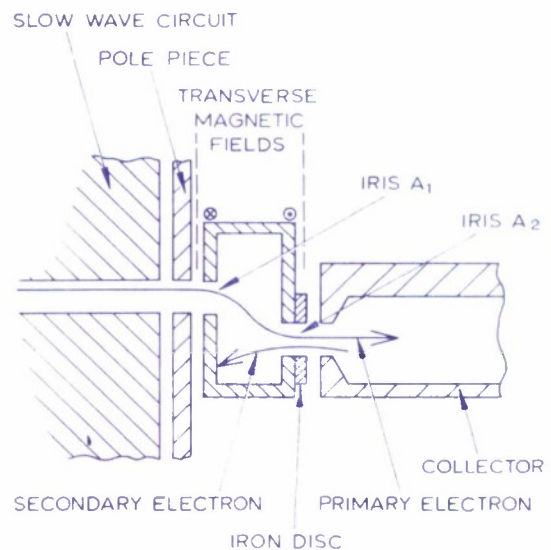


FIG. 3. Schematic arrangement of electron trap.

TABLE 1. T.W.T. Parameters

Operating Conditions	Frequency (GHz)	Pierce Parameters		
		<i>b</i>	<i>C</i>	<i>QC</i>
$V_o = 20$ kV	6.57	2.12	0.0480	0.525
$I_o = 1.4$ A	6.61	2.94	0.0450	0.599
$I_o/V_o^{3/2} = 0.5 \times 10^{-6}$	6.65	3.71	0.0430	0.650
$V_o = 24$ kV	6.42	0.65	0.0560	0.285
$I_o = 1.16$ A	6.46	1.60	0.0510	0.345
$I_o/V_o^{3/2} = 0.312 \times 10^{-6}$	6.50	2.68	0.0470	0.405
$V_o = 30$ kV	6.33	0.67	0.0600	0.164
$I_o = 0.93$ A	6.37	1.58	0.0546	0.200
$I_o/V_o^{3/2} = 0.179 \times 10^{-6}$	6.41	2.75	0.0491	0.245

$$b = \frac{1}{C} \left[\frac{U_o}{v_p} - 1 \right] \quad C = \left[\frac{I_o K}{4V_o} \right]^{1/3} \quad QC = \frac{1}{4C^2} \left[\frac{\omega_q/\omega}{1 + \omega_q/\omega} \right]^2$$

where K = coupled impedance of the slow wave circuit

ω = operating frequency

ω_q = beam plasma frequency

v_p = phase velocity of the circuit wave

U_o = velocity of unmodulated electrons

Fig. 4 shows the measured transverse field. By careful adjustment of the position of the iron discs it was possible to arrange for the integrated field to be zero. This was necessary to ensure that there was no net transverse velocity remaining on the beam as it entered the collector.

Details of the electron trap and collector assembly are shown in Fig. 5.

Experimental Results

Introduction

Collector depression experiments and noise measurements were carried out keeping the beam power ($V_o I_o$) constant at 28 kW with various values of beam perveance. In all the experiments the drive was adjusted to give saturated output. For each value of beam perveance results were obtained over the power bandwidth.

Efficiency Enhancement

Results obtained with the T.W.T. operating at the centre frequency for each beam voltage are shown in Fig. 6 where the efficiency enhancement factor

$$\left[1 - \frac{V_c I_c}{V_o I_o} \right]^{-1}$$

is plotted versus collector potential. The function

$$\left[1 - \frac{V_c}{V_o} \right]^{-1}$$

is the maximum possible enhancement factor, only obtainable when no current is intercepted. Current intercepted at the electron trap accounts for the difference between I_c and I_o , and the separation between the dotted curve and the experimental results shows the deleterious effect this had on the enhanced efficiency.

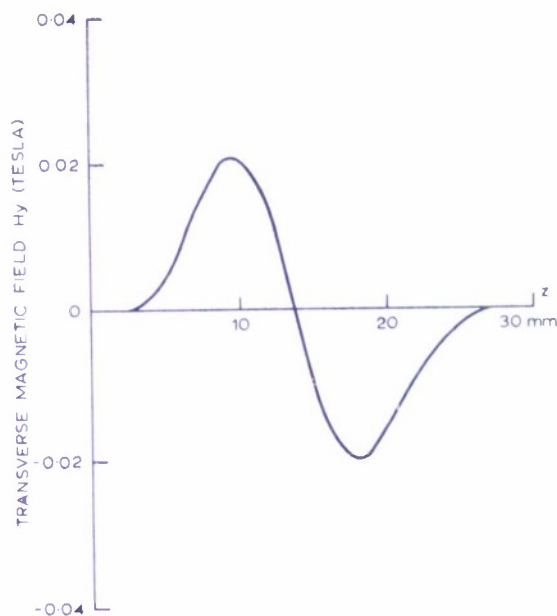


FIG. 4. Transverse magnetic fields.

The potential at which the collector rejected the slowest primary electrons effectively determined the maximum efficiency enhancement. In general, the electron energy distribution is such that high efficiency tubes permit less improvement by collector depression. This is shown in Fig. 7 where the results are plotted to show the collector potential for maximum efficiency versus the intrinsic efficiency η_o . Also shown, is the resultant enhanced efficiency.

Experiments over the power bandwidth showed that the depression of collector potential for maximum efficiency enhancement was less at the higher frequencies and greater at the lower (lower values of the

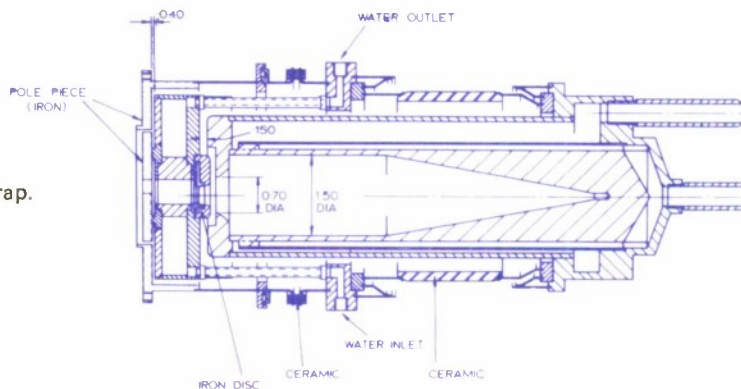


FIG. 5. Collector and electron trap.

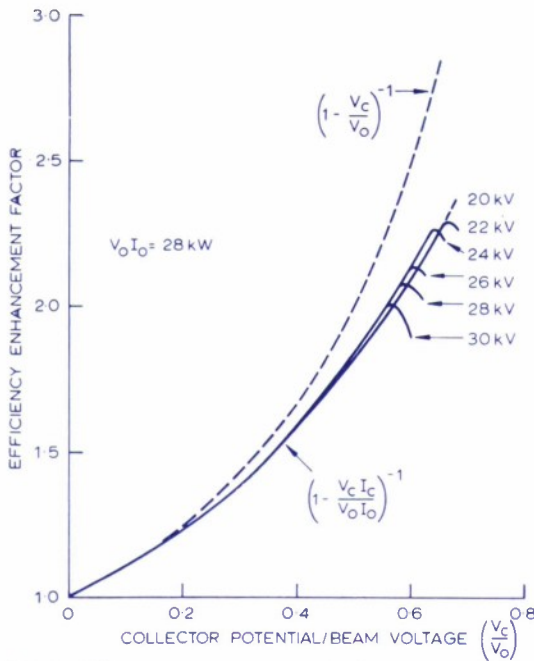


FIG. 6. Efficiency enhancement factor versus collector potential.

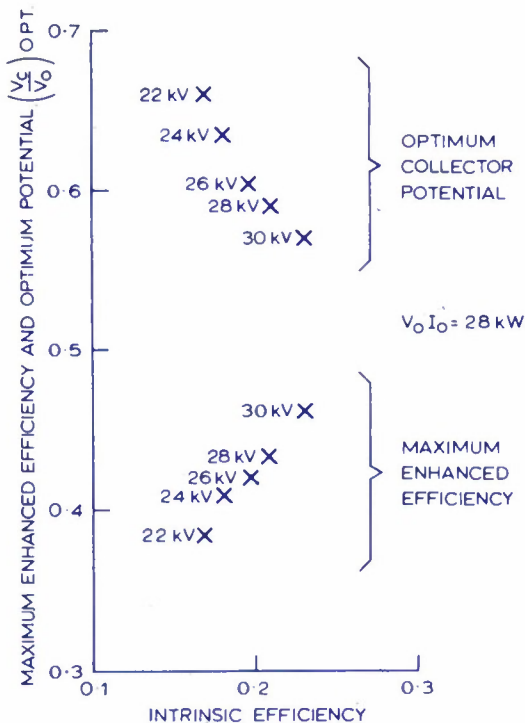


FIG. 7. Maximum enhanced efficiency and optimum collector potential versus intrinsic efficiency.

velocity parameter b). Fig. 8 shows the measured values of optimum collector potential versus b . From these results it is clear that when a T.W.T. is required to operate over a large part of its power bandwidth, the maximum collector depression that should be applied is that which is suitable for the highest working value of b . Optimisation of the efficiency enhancement at the centre frequency would result in a large proportion of the beam electrons being rejected by the collector with a consequential rise in power dissipation in the trap and drop in enhanced efficiency when working nearer the high frequency band edge.

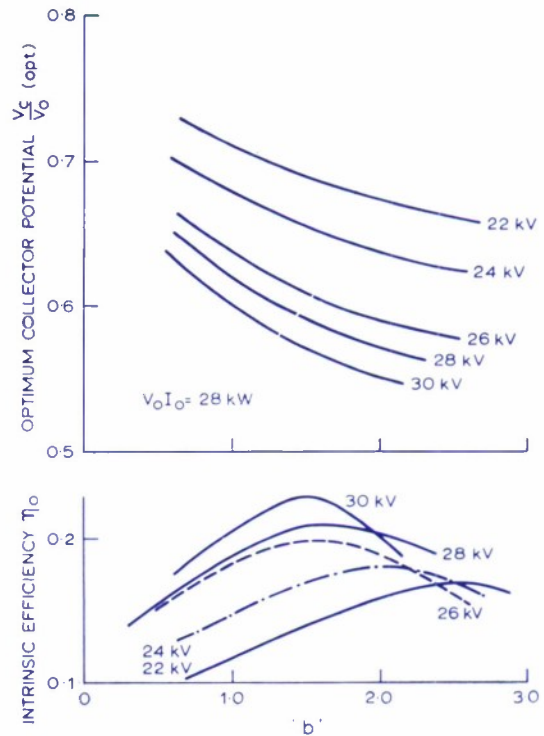


FIG. 8. Intrinsic efficiency and optimum collector potential versus ' b '.

Noise Performance

Fig. 9 and 10 show the results of a.m. noise measurements from 0.5 kHz to 120 kHz and it can be seen that the electron trap reduces the noise by at least 10 dB over the whole spectrum, and is independent of the collector potential.

The effectiveness of the electron trap was such that the current to the slow wave circuit never exceeded 3 mA (0.3% I_0) at any value

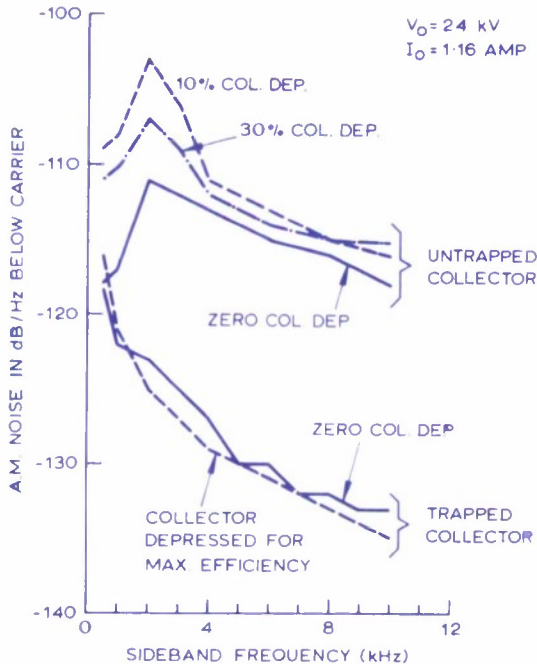


FIG. 9. A.M. noise spectrum (0.5 - 10 kHz).

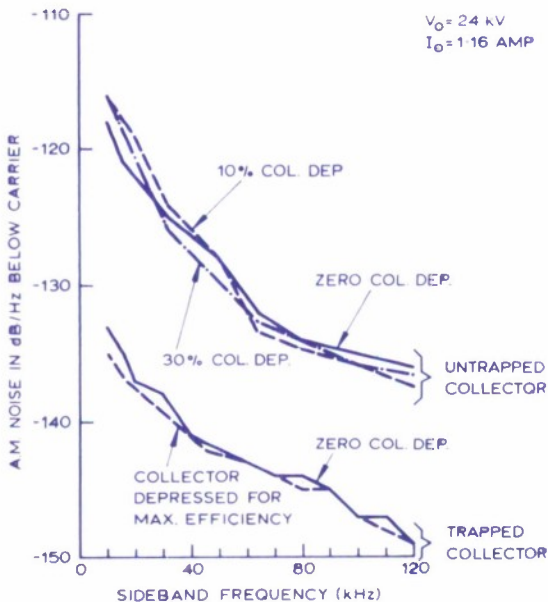


FIG. 10. A.M. noise spectrum (10 - 120 kHz).

of collector potential. In earlier experiments without the trap the collector potential depression that could be applied was restricted by the high interception currents on the slow wave circuit and the modulating anode of the gun, especially at the higher values of beam perveance. Hence it was not possible to operate with maximum efficiency enhancement.

Conclusions

Over the range of parameters used in the experiments it has been shown that, for T.W.T.s with untapered slow wave circuits, higher intrinsic efficiency permits less enhancement by collector potential depression. In spite of this the maximum enhanced efficiency increases with the intrinsic efficiency.

The results in Fig. 7 suggest that an approximate relationship between the optimum collector potential and the intrinsic efficiency is

$$\left[\frac{V_c}{V_0} \right]_{\text{opt}} \simeq 1 - \sqrt{\eta_0}$$

and provided interception currents are kept reasonably low, the maximum enhanced efficiency is

$$\eta_{\text{max}} \simeq \sqrt{\eta_0}$$

It has also been shown that by preventing a flow of secondary electrons through the slow wave circuit in the reverse direction to the main flow, the a.m. noise output was reduced by at least 10 dB over the sideband spectrum from 0.5 kHz to 120 kHz. An electron trap using transverse magnetic fields is shown to accomplish this very effectively, and results in making the noise performance independent of the collector potential.

Acknowledgements

The author wishes to acknowledge the assistance of J. Firkins and A. Manley in the work of constructing experimental T.W.T.s and obtaining many experimental results.

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- (2) Bryant, M. O., *British Communications and Electronics*, **9**, No. 8, pp. 590-591, 1962.

CURRENT CONTROL AND SURVEILLANCE PRACTICE IN ROYAL NAVAL MAIN SURFACE SHIP PROPULSION MACHINERY

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Ship Department, Bath



Captain Thwaites passed out from RN Engineering College, Plymouth, in 1948, and then served in two aircraft carriers before attending the RNC Greenwich for the Advanced Ordnance Engineering Course. He was employed in development of automatic gun mountings and later as Project Officer for gyro stabilisers. On formation of the Weapons Electrical Specialisation he was trained in electronics and radio prior to service in H.M.S. *Lion*. For three years he was Project Engineer for Gun Control Systems. Following a period in H.M.S. *Phoebe* he joined Ship Department, Bath, where he heads the specialist section dealing with Control of Main Propulsion Systems.

Abstract

The reasons for the introduction of remote control together with new factors arising are reviewed and followed by an account of the philosophy in design. Basically control and surveillance is from a Ship Control Centre from which extensions to the controls are led to the Bridge. Manual control is retained locally at the machinery installation as an alternative.

Pneumatic systems are now no longer being fitted, their place being taken by electronic systems, interfacing with pneumatic and hydraulic power actuators. These newer systems have yet to be tried out at sea.

Development in surveillance involves revised techniques in watchkeeping and presentation of information.

Reasons for Use of Remote Control

Apart from such devices as automatic feed regulators for steam generating plant, pressure governors, speed governors and other localised control instruments there was little automatic overall plant control equipment fitted in the Royal Navy prior to the advent of nuclear weapons. Whatever controls were fitted were operator supervised and manually adjusted to suit conditions prevailing from time to time. Nuclear fall out presented a severe problem to such a situation as huge quantities of air contaminated by radioactive particles would be ingested by the combustion systems of main propulsion plant with harmful effect on the watchkeepers. Similar hazards were presented by conditions of chemical and biological warfare. A pressing operational need for remote control of the machinery concerned was thereby established and programmes of work started to introduce effective remote control with existing plant and later with new designs.

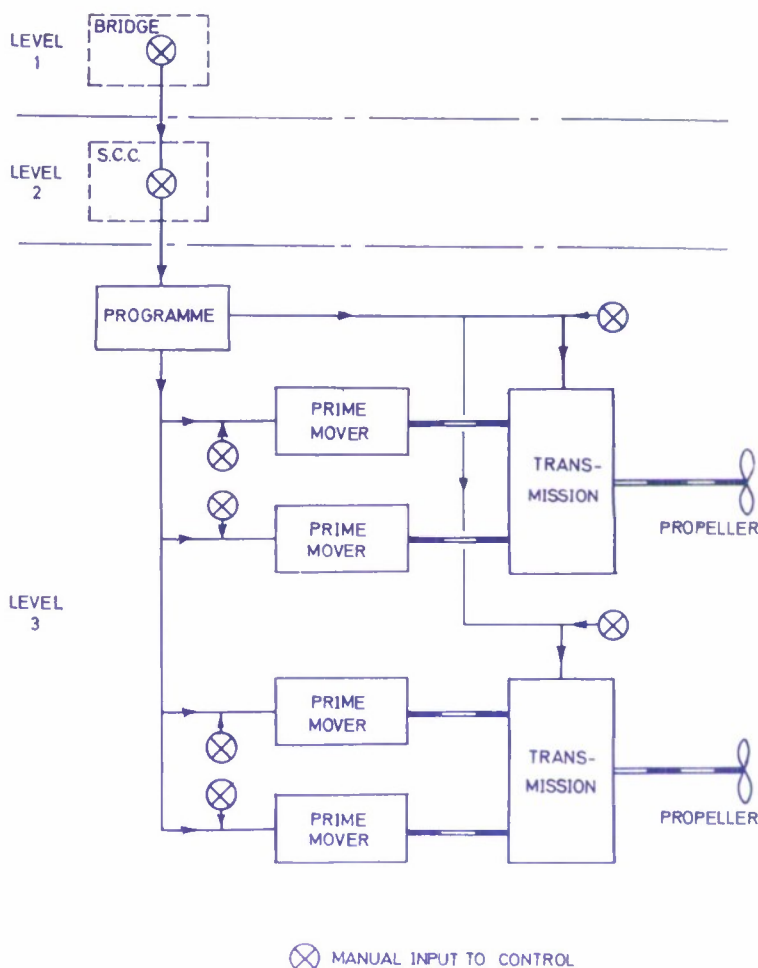
FIG. 1. Plant and Plant Control Philosophy.

Other factors also influenced the programme:

- (a) Predicted shortages of suitable manpower to serve at sea.
- (b) Realisation of the significant cost of manpower, arising from life-cycle costing of warships.
- (c) Trends towards smaller ships containing relatively more equipment.
- (d) Shorter reaction times encountered in modern plant, together with reduced safety factors in design.
- (e) Need to establish a modern environment for engineering staff.

Philosophy

Early attempts at automation in warships had aroused considerable interest but also illustrated the penalties of unreliability and increased technical maintenance manpower awaiting the unwary. Above all, the ability to continue to fight the ship under adverse conditions of action damage remained paramount. This has resulted in making haste slowly, relevant to merchant ship practice. Even ignoring the factor of wartime damage it still remains necessary to retain a sufficiently large complement to cope with the normal hazards of ship-board life—fire, flood, collision—as well as with potential plant failures. In this latter connection it is realised that duplication or triplication of vital plant or even of only control systems is a heavy price to pay for increased reliability of operation. Clearly a



balance between automation and human operation must be sought and achieved.

Generally speaking the balance achieved has avoided triplication and has made use of more than one propulsion shaft per ship, and/or more than one engine per shaft. This reduces the likelihood of overall plant failure both from the point of view of power and of control, and limits it in the first instance to a loss of one of two or one of four parallel systems. Within each system levels of control are arranged to reduce the vulnerability of the control itself. Fig. 1 illustrates this philosophy: prime movers are shown as four blocks transmitting power into two transmissions each driving a separate propeller. Control is exercised from three alternative levels, starting at the bridge and feeding *via* the Ship Control Centre through the block labelled

"Programme" to the prime movers and transmission system. Local (Level 3) control is provided by separate inputs at the prime movers and transmission. Such a system permits a retreat from Level 1 *via* Level 2 to any part of Level 3 as circumstances dictate. The significance of the "programme" is to relate the inputs from Level 1 or 2 to the various plant block characteristics in terms of amount, rate and time so as to provide optimum performance and at the same time avoid damage to the plant. Level 3 involves no programme and depends for success on the intelligence, training, and correct drill of the operator. In some particular cases elementary mechanical interlocks are included even at this level.

It is relevant here to discuss more deeply the roles of Bridge and Ship Control Centre (SCC). In brief the Bridge Control involves only a feedback of output parameters to the operator, *viz.*: shaft speed and direction, ships speed through water, and assumes correct operation of connected plant. The SCC control is provided with plant surveillance in terms of analogue gauges and preset level operated alarms and warnings as well as output parameters. Thus the SCC operator can observe plant behaviour, monitor the effect of control input and adjust it if necessary to avoid dangerous conditions. This should only be needed if the controlled machinery has become partially defective and is operating abnormally.

Local (Level 3) control is provided as the fallback position in the event of failure of the "programme" or of the control links. More extensive instrumentation is in some cases provided at the local control position to permit safer manual operation. A slower reaction time to propulsion orders must be expected at this level of control, and it should be regarded only as a "get you home" facility with limited manoeuvring capability.

Control Medium

Selection of control medium in the Royal Navy was concerned initially with suitability for steam propulsion plant. Pneumatics was chosen for reasons of compatibility with prevailing conditions in machinery spaces and boiler rooms together with its energy potential for powering the large number of actuators necessary to steam plant operation. Bottled emergency air supplies were fitted to overcome the risks of electrical supply failure temporarily stopping the air compressors.

Such systems, obtained from various manufacturers were fitted widely and operated satisfactorily.

Introduction of Combined Steam and Gas—COSAG—plant added gas turbines to the existing types of steam installations. While retaining pneumatic controls hydraulics were then employed to operate the fluid couplings and clutches required to connect and disconnect the various prime movers to and from the reversing gear trains associated with these gas turbines. The selection of hydraulics for this purpose was mainly associated with the need to provide positive positioning of these mechanisms at all times.

The advent of all gas turbine plant for propulsion then materially changed the factors influencing selection of control media. Solid state electronics were by now available and offered practical advantages in size and power requirements compared with their thermionic predecessors. Gas turbine plant requires a high degree of logic in controlled operation, but power actuation is reduced to a minimum on the turbine itself and in the transmission system. Solid state electronics is a most suitable medium for logic. It can be battery supported in emergency and is amenable to built-in testing by less expert diagnosticians. Repair by replacement is simplified. At this point therefore, a change was made in selected control medium and a programme commenced to develop an electronic control system interfacing with pneumatic and hydraulic actuators. Such systems are now being installed in new ships building and are tailored to suit the operating characteristics of the plant concerned.

Surveillance Systems

The point has already been made that two kinds of surveillance presentation are provided in the SCC—analogue, and preset alarms and warning lamps. In the last of the COSAG installations the control console became a very extensive unit incorporating large numbers of analogue gauges and requiring a considerable number of experienced watchkeepers for its operation. The console is illustrated in Fig. 2. H.M.S. *Exmouth*, an experimental gas turbine installation, produced a smaller console but relatively large for a single screw vessel. The next design was for H.M.S. *Sheffield* and is the first of the solid state electronic systems—see Fig. 3. Analogue gauges are reduced to a minimum in number and backed up by

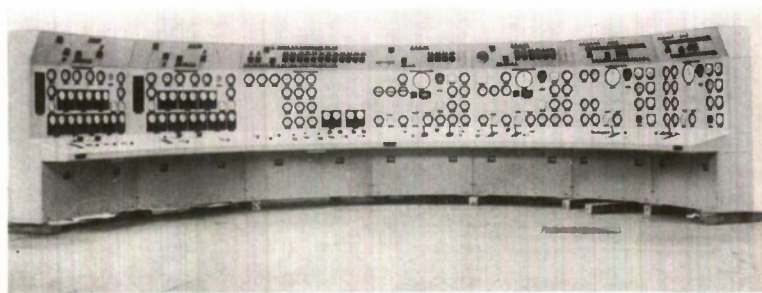


FIG. 2. Control Console
H.M.S. *Exmouth*

“alarm” and “warning” windows illuminated to alert the operator to an abnormal condition. Alarms denote that an emergency has arisen endangering the equipment, and in most areas indicates action automatically initiated *e.g.*, to shut down plant or start alternatives. Warnings indicate and draw attention to an abnormal condition not covered by an alarm for which early remedial action is required. Auxiliary systems are covered by similar means but possess their own automatic watchkeeping panels; an alarm simply indicates automatic shut down, and cause must then be diagnosed locally.

The system described no longer requires the operator to supervise gauges in the same way as formerly. The warnings and alarms alert him by flashing lamps and audible warnings, drawing attention to the defective area. This change in concept introduces different factors in selection of skill and employment of watchkeepers. It permits the use of a “shift” engineer leaving watchkeeping to a lower level of semi-skilled personnel.

The system does not incorporate automatic data logging, nor does it provide much to assist the watchkeeper in remembering the

significance and geography of the plant. Subsequent design has progressed towards the use of mimic diagrams and automatic data logging. There is no doubt that mimics can provide a significant aid to operators of complex plant both in assessing operation and in deciding remedial action. Automatic data logging is an aid to providing accurate historical data, showing trends and releases manpower to perform more intelligent tasks than data collection alone. It may also reduce the manpower needed for continuous plant operation.

As usual, a balance has to be struck between cost of equipment and the alternative manpower. In a ship of frigate size accommodation is at a premium, engineering staff is numerically limited and it seems that the balance is in favour of automatic remote surveillance for propulsion and auxiliary machinery. In larger vessels there is a significant increase in generating capacity and auxiliaries. This points to an increase in the number of men visiting widely spread machinery compartments and available for fighting the ship, but their task can advantageously be eased by a judicious application of automatic remote surveillance with data logging.

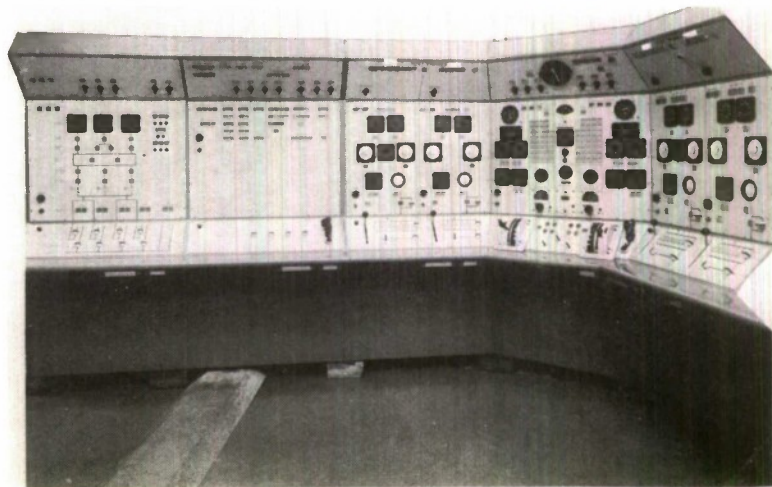


FIG. 3. Control Console
H.M.S. *Sheffield*

Development State

The control equipment chosen for naval application is a development of the commercial Hawker Siddeley Dynamics Engineering Co. Ltd., modular electronic system. A programme to navalise the commercial modules was undertaken and has resulted in the system whose console was illustrated earlier (Fig. 3). The system has a single control lever per shaft input to actuate a frequency analogue servo system providing pulsed output to stepper motors. Related programmes for propeller pitch and gas turbine throttle opening are aimed at achieving an approximately linear relation between input lever position and shaft revolutions above that corresponding to turbine idling speed. To achieve slower ship speed the propeller pitch is reduced and eventually reversed to provide astern power. Separate start/run/stop facilities are fitted for each of four engines together with smooth change-over between engines driving the same shaft. At the zero position of the control lever a shaft brake can be applied by a sideways movement through a "gate". The system is designed on a "fail-set" basis.

A series of standards are employed to perform the necessary functions *e.g.*, power supply, frequency comparator, actuator drive, logic sequencing, surveillance, etc. These are "plug-in" units fitted in chassis which are wired into the console.

A test and monitoring system is superimposed on the control system. This enables on-line testing of modules on a "go/no-go" basis. Spare modules are kept to hand in case of failure. This system is designed for operator first-line maintenance, the operator being a propulsion engineering mechanic with minimal electrical training. Inter-module failures need more skilled electrical engineering expertise for diagnosis and this is provided by the ships electrical engineering staff. The console is designed for rear access which permits test and monitoring to proceed without disturbing the front panels.

Surveillance Channels are wired individually *via* appropriate modules from sensor to warning light/acceptance switch. In the event of a pre-set limit being exceeded the appropriate lamp flashes until the operator accepts it by depressing the lamp window when it remains illuminated until the parameter concerned returns to normal. Alarm lamps are red, warn-

ings yellow. Where state lamps are fitted these are green. A test circuit is available to check each sub-system.

The first systems have now been built and tested at the factory. Most design areas were validated at factory test. However, some sub-systems were unsatisfactory and required correcting modifications to be generated proved and fitted; electrical interference was the main culprit. Installation is now proceeding. Setting to work will start later this year followed by sea trials.

Further Development

As already mentioned there is now a greater use of automatic data logging. A survey of available equipment was made two to three years ago, and as a result trials were carried out in H.M.S. *Hecate* and in a shore test facility using the commercial Decca ISIS 300 surveillance system. These trials have proved very satisfactory and a ship design incorporating this warning equipment with the Hawker Siddeley Control and Alarm system is now proceeding. The system also offers the advantages of reduced ship cabling as it employs multiplexing.

Apart from this basic system described above, work is also proceeding to design a modern d.c. servo system for application to control of propulsion machinery in smaller ships.

At the present time no work is being done on the application of digital computers to surface ship propulsion machinery control in the Royal Navy. However, progress in merchant ships in this field is being followed with keen interest. As costs of small computers reduce this approach becomes more attractive. Generally for all systems sensors form a weak area in achieving satisfactorily reliable solutions and actuators do not present as wide a choice as is desirable. However ingenious the signal processing and reliable the actual control programming may be, the system will only be as good as its input sensors and output actuators. All our experience at present indicates that there is much room for improvement in sensors and for development of actuators, particularly in the electrical field.

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PRECISION HEAT CONTROL FOR LARGE TANKS

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Introduction The testing of submarine lead-acid cells necessitates the provision of a constant temperature environment throughout the test programme which may extend over many years. As each submarine lead-acid cell weighs approximately one half-ton, and there may be up to 12 cells in a particular test configuration, the only practical way to provide adequate control of the experimental environment temperature is by surrounding the cells with a fluid of high thermal capacity to act as a heat transfer medium. Including the tank itself, the weight of the assembled experiment may be up to 10 tons and this mass has to be maintained at a given temperature setting to an accuracy of $\pm 0.5^{\circ}\text{F}$, summer and winter, possibly for 10 years or more.

In the Battery Research Bay at the Admiralty Engineering Laboratory, large tanks 4 ft. in height and width, and up to 12 ft. in length, are used to contain the submarine lead-acid cells under test. Water, which has the merits of high thermal capacity and extremely low cost, is used as the heat transfer medium. Testing of submarine lead-acid cells has been in progress at AEL for many decades, nevertheless control of the test temperatures was rather less than satisfactory. The writer's attention was drawn to the shortcomings of the methods in use with a request to improve the test conditions if possible.

At this time (1963) a new experimental item was received consisting of submarine lead-acid cells of the type used in H.M.S. *Dreadnought*. A new tank was being prepared for the test programme and an opportunity of

studying the temperature controlling systems presented itself.

In general the submarine lead-acid cells under test are maintained at a temperature of 80°F . At this temperature level, heat has usually to be supplied to the tank as it is normally above the ambient temperature for most days of the year. Under certain test conditions the cells generate heat, which if it exceeds the amount of heat lost by the tank to its surroundings, will necessitate removal. Attention was therefore primarily directed at the heating systems being used in the tanks.

Early Heating System The earliest method of heating the large tanks was by placing radiant type electric heaters under the slightly raised tanks. This primitive method was electrically dangerous and very inefficient since most of the generated heat was removed to the surrounding air by convection and lost. The response of the system was exceedingly slow. Nevertheless this method enjoyed a long period of usefulness, the last such tank with this particular heating system was removed in 1966 after many years of service. There were some advantages in the use of this method, e.g. ease of replacement of the heaters, and the heat input was at the base of the tank. This contributed to the uniformity of heating within the tank. The large amount of heat required necessitated the use of large electrical contactors with the attendant arcing and the risk of explosion from hydrogen gas liberated during the charging of the submarine cells.

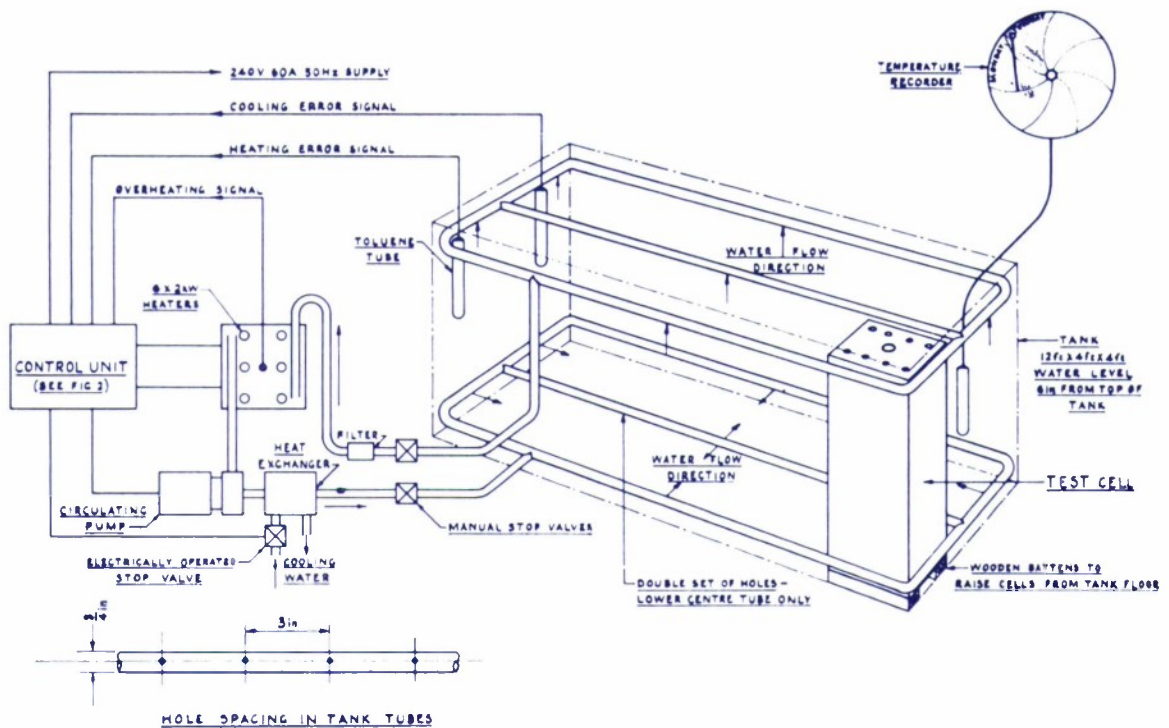


FIG. 1. Precision Tank Heating Schematic.

Standard Heating System

Another method of heating was devised later on with the advent of mineral insulated cables, e.g. Pyrotenax magnesium oxide insulated cable with an external bare copper sheath. This was more efficient than the preceding method in that all the heat generated passed into the water contained in the tank but, as will be seen later, was actually a retro-grade step in some ways. The calculated lengths of Pyrotenax cable required for the heating of the particular size of tank was affixed to large double-banked brass panels, in zig-zag fashion, by a large number of clips. The panel assemblies, two in number, were almost the full length and half the height of the experimental tank and were fitted at the inner surfaces of the two long sides. The ends of the cables were brought out of the water to a junction box and the ends were carefully sealed to prevent loss of insulation resistance through the penetration of water. A control box was fitted with switches for the series-parallel operation of the various sections of the heating cable, together with fuses and indicating lamps. The last such arrangement as shown in Fig. 3 was used for the submarine

cells of the type used in nuclear submarines and although the requirement was urgent, the actual manufacture and installation took three months to complete. Within one week of commissioning one of the cables broke down in insulation. This fault was a very common one, and when such a fault occurred meant draining the tank, removing the experimental cells, disconnecting the cables and removing the heating cables and panel for repair. After repair the opposite procedure was necessary to refit the heating panels and re-start the test programme. In this particular case no great harm was done but a breakdown in the middle of a long test could be much more serious, since it is generally impossible to repeat the test a second time.

A more serious disadvantage was the large difference of temperature between the top and bottom layers of the tank. This defect was inherent in the method of heating and arose in the following way. The heat energy from the heating panels created a narrow vertical flow of heated water which rose and spread out on the top level of the tank as a shallow heated layer. Being warmer than the lower mass of water there was no movement

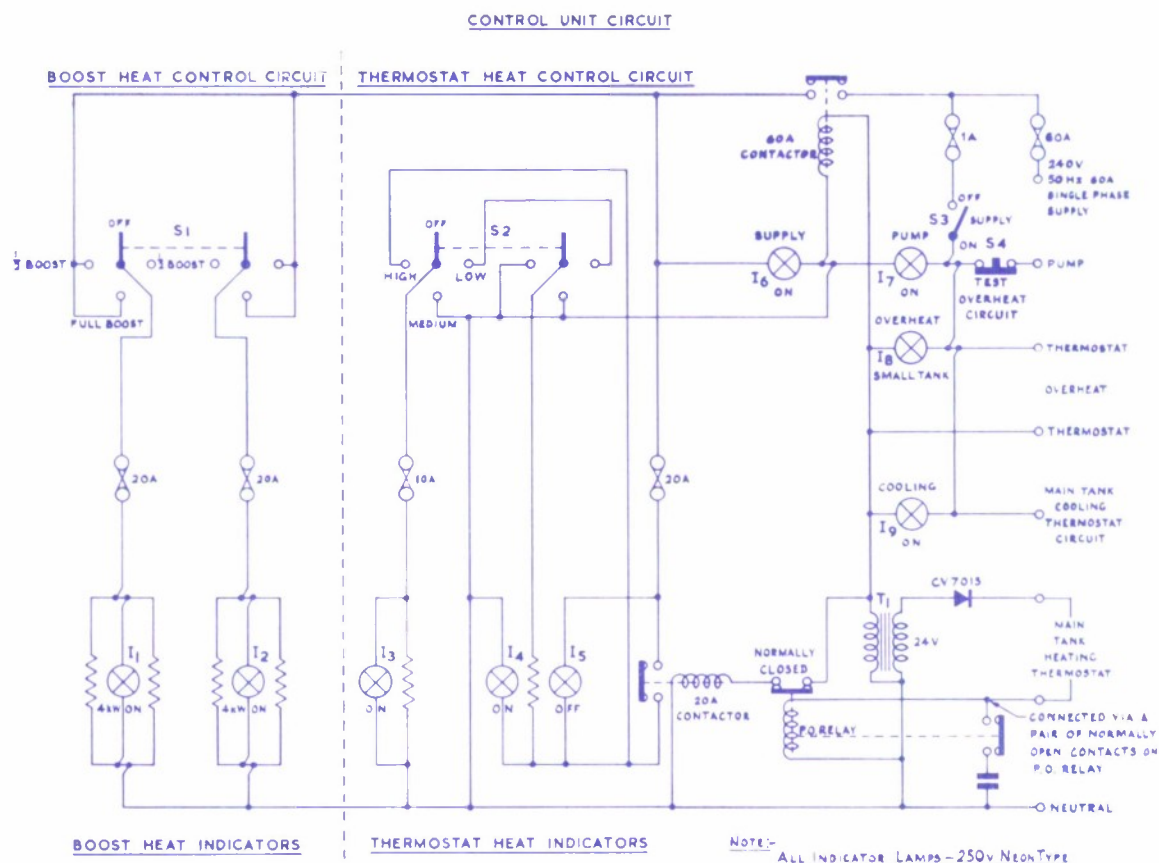


FIG. 2. Precision Tank Heating Circuit.

downwards owing to the difference in density, and the resulting temperature gradient was a stable arrangement. At the top of the tank, and dipping below the water for a few inches, was situated a toluene tube for detecting the temperature change. This temperature sensor, sensitive to a temperature change of a few hundredths of a degree Fahrenheit at its operating point, then cut off the electrical supply to the heaters as soon as the top layer of water reached the required temperature. The main bulk of the water, especially at the bottom of the tank and that situated between the two rows of cells contained within the tank was completely unaffected by the heating process owing to the very feeble and ineffectual convection currents created in the water. Thus even after the tank had settled down to steady state conditions, a differential of temperature of 20° - 30° Fahrenheit could exist, between the top and bottom layers of the water in the tank, during cold weather.

Another disadvantage was the low heating capacity of the cable which meant that the time required to bring a tank to steady state conditions from a cold start was excessive. A grave safety risk also arose in the case of corrosion of the cable outer sheath for the water surrounding such a weak point could be raised to the potential of the supply mains until the leakage current rose to a value sufficient to blow the protective fuse. Corrosion of the outer sheath of these cables is a common occurrence due to the operating conditions, the sulphuric acid content of the tank water and the galvanic action between dissimilar metal parts of the heating panels. As stated previously this was the heating system used for the tank containing the new experimental item comprising submarine cells of the type used in nuclear submarines, and the reason it was fitted in this case was that no better practicable heating system was known at the time.

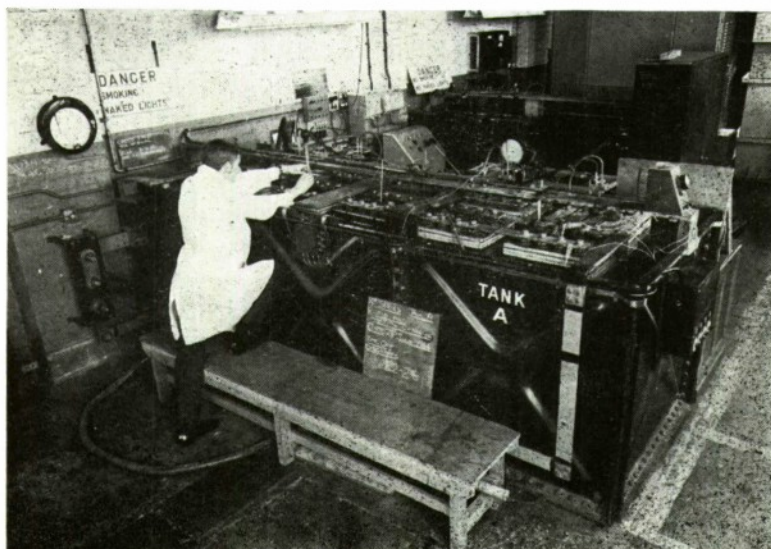


FIG. 3, Standard tank heating using pyrotenax cable in the foreground, prototype tank heating system at rear.

Principles of Correct Heating of Large Tanks

Consideration of the preceding points led to the drawing up of the following list of requirements for the heating of large tanks:

1. Heating transfer medium to be uniformly and vigorously circulated throughout the tank.
2. Heat input temperature and main tank heating medium temperature differential to be as low as possible.
3. Heat input to be given at frequent intervals, *i.e.* frequent small pulses of heat input rather than infrequent large pulses of heat input.
4. Heat input to be injected at the tank bottom.
5. Large thermal over-capacity to allow for initial rapid heating of tank from cold start.
6. All heating elements to be located outside the main tank.
7. Rapid replacement of heating source, when necessary, without causing cessation of experimental work.
8. Complete electrical safety for tank operators.
9. Complete protection against arcing or sparks from electrical contacts causing explosion of hydrogen gas from on-charge gassing cells.
11. Long term reliability and minimal maintenance essential.
11. Fail-to-safe devices for protection against all possible failures in heating equipment.

12. Universality of use of heating equipment for all large tank applications without modification.

Prototype Heating Unit

The principles listed were embodied in a prototype heating unit after considering the requirements one by one. Water circulation by convection was obviously quite unsuitable. Small reliable electrically driven water pumps were readily available, so that this method of circulating the water seemed suitable providing a water pump of suitable construction to withstand the heat and the sulphuric acid content of the tank water was used. However single point injection and removal of the water would not be sufficient of itself to ensure a proper circulation of water within the tank. To overcome this difficulty, a water-circulation circuit was designed as shown in Fig. 1. This design was adopted to ensure a uniform cross-sectional flow of water throughout the tank. There were two design alternatives, one a high pressure hydraulic circuit, the other a low pressure hydraulic circuit. The high pressure circuit was investigated first, this required identical discharge holes along the length of the discharge line and the attraction of this design was that no difficult mathematical treatment was necessary for determining the size of holes required and any alteration necessary would be the same throughout the circuit. This design was rejected because with the type of pump used, the amount of water pumped depends on the pressure head supplied and

very rapidly falls off at the higher pressures. The high pressure would also find the weak spots in the external hydraulic circuit and cause leaking to occur. The most serious disadvantage of the alternative low pressure system was the calculation of the graded size of hole required to ensure uniform cross-sectional flow at all parts of the tank, and if this was not correctly computed initially, the difficulty of modifying the error. However a method of checking the amount of water discharged at any point was devised so that a practical solution was possible.

The low pressure hydraulic circuit design commenced from the assumption that a minimum of one complete circulation change of the tank water per hour would meet all the requirements for uniform heating. The largest size of tank used is 12 ft. long, 4 ft. wide and 4 ft. in height. Assuming this tank to contain the normal maximum number of cells for test, 12 in number, this enables the total amount of water to be calculated. The depth of water is approximately 3 ft. 6 in., thus the total tank volume is $(12 \times 4 \times 3.5)$ minus the volume of the immersed cells which is $(12 \times 3.5 \times 1.46 \times 1.17)$. The resultant amount of water used as the heat transfer medium is therefore 96 cubic feet or 600 gallons. A water pump of 720 gallons per hour was chosen to allow for this rate of pumping and moves 7,200 pounds of water per hour, but the electrical power consumed is only 170 watts. The low pressure system allows a pump of lower rating to be used, as explained previously, and avoids trouble due to cavitation at the impeller of the pump. To ensure a uniform cross-sectional flow, it was decided to deliver the supply water to many points simultaneously by means of a $\frac{3}{4}$ inch diameter copper pipe drilled with holes at intervals of 3 inches. The total area of the holes was arranged to allow for the full circulating capacity of the pump to be utilised. Similarly the water return circuit consisted of a $\frac{3}{4}$ inch pipe drilled with the same distance of hole separation. In this case however the holes were made slightly larger to compensate for the difference between the inlet pressure and the outlet pressure of the circulating pump.

Consideration was next given to the best point of entry for the heated supply water. Since any slight variations of inlet water temperature would cause beneficial independent convection currents, it was decided to supply the inlet water to the bottom of the tank and

thus avoid temperature differentials and static temperature layer formation. The return water circuit must then be taken from the top layer of water and this would ensure that the temperature of this layer would be more uniform owing to the continual removal of water. The temperature sensor had to be placed, as usual, a few inches below the surface of the water; this being the only practical position for a toluene tube.

Attention was next paid to the heating unit necessary. As space is always at a premium in the Laboratory, it was necessary to reduce the heating unit to a minimum size. A kettle heating element of 2.0 kW rating and of small physical size was found in the Naval Stores Rate Book. A maximum power input was set at 12 kW to permit the use of a 60 ampere supply, this being the maximum permitted on a single phase supply. This would give a rapid heat input when required and only necessitated the use of six such elements. These were arranged in two staggered rows, one row above the other to avoid heating of the upper elements by the lower elements, to achieve the minimum volume. It was found that the assembly of elements could be accommodated in a small copper tank of dimensions 14 ins. by 9 ins. by 9 ins. Once these major design points were finalised a console 4 ft. in height was designed to contain all the necessary components and electrical circuits. A top sloping panel was provided to carry all the switches and indicator lamps whilst the compartment to the rear of this panel contained all the other electrical parts. See Fig. 2 for the electrical circuit. As the main point of entry was to be at the base of the tank, the outlet of the circulating pump was positioned to be opposite a suitable $1\frac{1}{2}$ in. diameter pipe inserted in the bottom part of one of the tank panels.

Initially the water flow in the small heating tank was arranged so that the circulating pump removed heated water from the bottom of the heated tank and the cooled water returned at the top so that the circulating convection currents in the heating tank would ensure uniformity of water heating. This method failed because of dissolved air in the water which resulted in an air lock at the top of the heating tank when in operation and this uncovered the heating elements. These then overheated and ejected the connecting plugs of the heating elements. The flow and return pipes were therefore altered in the heating tank by adding an extension pipe to each so that the pump

took its supply water from the top of the heating tank and the return flow entered at the base of the heating tank. This ensured a vigorous circulation of the water within the heating tank and at the same time had the advantage that any release of dissolved air was taken out by the circulating pump and vented to atmosphere *via* the outlet pipe in the main tank.

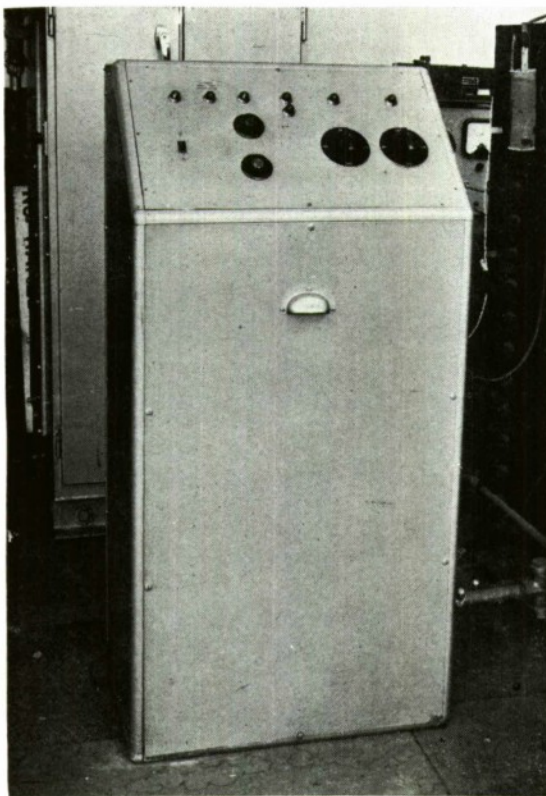


FIG. 4. Prototype Control Console for new heating system.

In order to avoid the danger of an excessive temperature rise in the heating tank a safety thermostat was fitted and set to an operating point approximately 5° Fahrenheit above the temperature of the main tank. Thus in the case of malfunctioning, the supply would be removed from the heating elements and an indicator switched on to warn the operator.

All the interconnecting pipes within the unit and to the main tank were arranged to offer minimal resistance to water flow, in addition a filter was fitted on the inlet from the main tank in order to prevent the entry of foreign particles to the circulating pump and possible damage to the impellor or stop-

page of the pump. Stop valves were also fitted in the inlet and outlet pipes of the main tank to be closed for removing the control console heating unit when necessary. The two interconnecting pipes between the heating unit and the main tank were selected from a tough reinforced rubber range and secured in position by large screw hose clips. Thus the removal and replacement of a heating unit could be performed within a quarter of an hour. No loss of experimental work time need therefore result even in the case of complete breakdown.

It was originally intended to use thyristors for controlling the power supply to the heaters but this was too expensive at the time owing to the relatively high cost of these devices. Contactors were therefore used and it was felt that as they were completely enclosed and also protected by the console, which is remote from the cells, little risk of explosion would arise in practice. The cost of thyristors is now very much reduced and the earlier restrictions no longer apply. This form of control would be superior.

Access to the various components in the heating console for maintenance was made easy by the use of a large front panel affixed by Dzus fasteners. Any components therefore can be replaced in a short time if necessary. Fig. 4 shows the complete console, and Fig. 5 the interior arrangement.

Performance of New Heating System

After the first few weeks of operation the circulating pump gave trouble. This was traced to the fact that the pump employed aluminium bearings and these were rapidly destroyed in spite of the manufacturer's assurance that the pump was suitable for the proposed service. Substitution of a more suitable pump has resulted in complete reliability over the last few years. Some heating elements also failed owing to the hardness of the tank water but this is easily avoided by using demineralised or distilled water which is readily available in the Laboratory. Otherwise little maintenance has been necessary.

The precision of temperature control has completely justified the original work and a record chart of the temperature over one week in winter is appended together with a corresponding record of a tank controlled by the old heating system (Fig. 6). The difference in performance requires no further explanation.

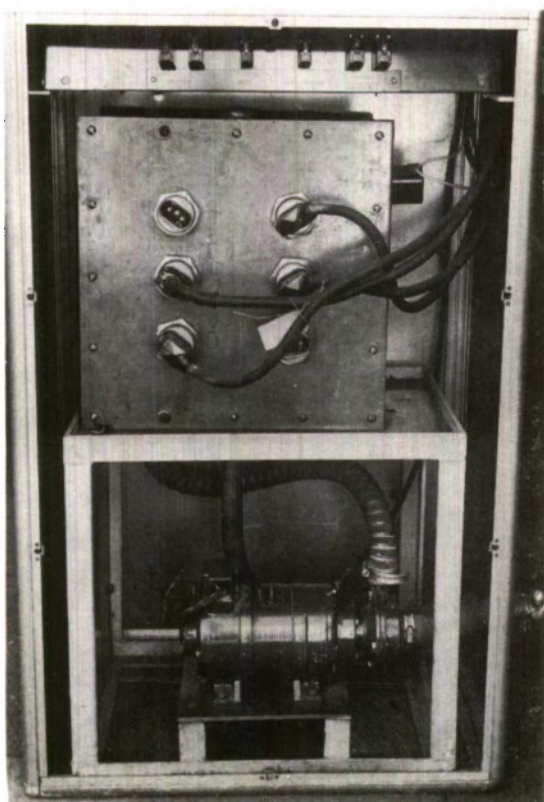


FIG. 5. Interior arrangement of control console.

Possible Improvements Originally it was intended to fit a heat input sensing circuit so that the heat input would be proportional to the ambient temperature. By this means the heat on/heat off time cycle would remain constant and the electrical energy supplied to the heaters would be suitably proportioned to allow this. As the ambient temperature rose the electrical energy input would be reduced accordingly. The concept behind this was that the tank heat losses at any temperature would be supplied by a heat input electrically adjusted to be just below the required amount and the small extra amount of heat would be switched in and out by the temperature sensor. This would ensure that no variation in temperature would occur in the tank. An anticipator circuit consisting of an auxiliary temperature sensor would also be required to prevent the stored heat energy of the heating elements

making the tank temperature rise after the electrical supply was removed. The ratio of stored heat in the switched elements would be low compared to that stored in the main tank but for the most precise temperature control this would have to be allowed for in the design. As will be seen from an inspection of the temperature chart, this refinement was not really necessary for the present application, and owing to complication was not incorporated. For more precise temperature control, say to 1/10th of a degree Fahrenheit, this extra control would be essential.

The use of thyristors is now feasible owing to the great reduction in cost, this would make heating control easier but the form of control would have to be limited to proportional control to avoid interference being injected into the supply lines, *i.e.* the thyristors would be switched in for complete cycles of a.c. operation and not controlled by phase shifting. Thyristor control would only be required for a power input of a maximum of 1-2 kilowatts to maintain a given temperature since the ambient temperature is normally about 65° Fahrenheit with a tank temperature of 80° Fahrenheit. The ambient temperature may however drop to 35° or less over a winter weekend when the normal heating of the Battery Research Bay is turned off for a continuous period of approximately 60 hours.

Another desirable feature that was not incorporated originally was the use of cooling for lowering the main temperature tank temperature when the cells are on high rates of charge or discharge. This cooling, which is especially necessary in summer when the ambient temperature rises to 70°-80° Fahrenheit, can easily be provided, if required, by passing mains water through a small circular tank containing a spiral coil fitted in the supply pipe from the heating console to the main tank.

Insulation of the main tank was also envisaged to reduce the heat losses from the main tank, with metal panels to protect the insulation and improve the appearance of the tank. These tanks are painted with bitumastic paint to prevent corrosion and present a somewhat sombre appearance. Suitable insulation materials were found for this purpose but the installation was not carried out. The cost of such insulation would be recovered within one year's running of a tank.

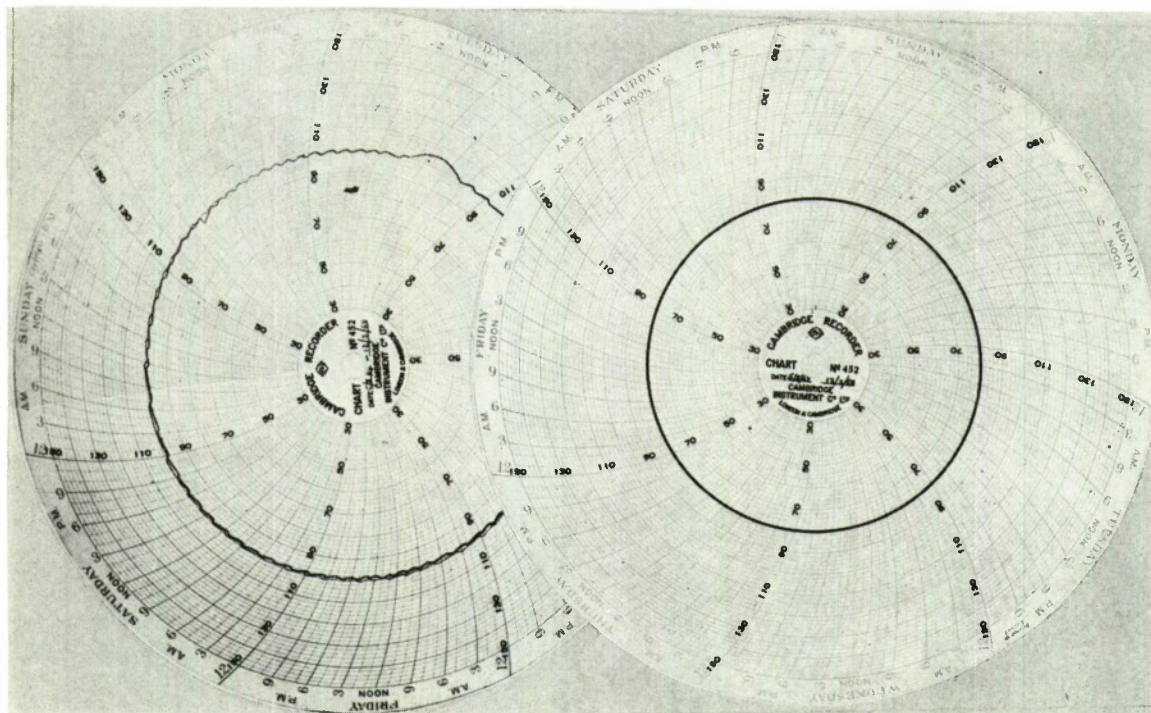


FIG. 6. Temperature variations in tanks over some period in tanks controlled by old heating system (left) and new heating system (right). Note that the controlled temperatures are 100°F and 80°F respectively but this does not affect the comparison.

Evaporation of the water from the main tank at this relatively high temperature amounts to many gallons per week and this was to have been reduced by the use of polyurethane or polystyrene foam spheres floating on the surface of the tank water. Trials of this preventive measure still await investigation.

Conclusions

The described heating system has been adequately demonstrated to be superior in every way to that used previously, and meets all the design criteria listed under "Principles of heating of large tanks".

APPENDIX

Normal Operation of Control Circuits

The circuit shown in Fig. 2 is assumed to be connected to a suitable single phase mains supply and to be controlling the heating system from a cold start with all functions normal. On closing the supply switch S3, the 240 volts a.c. supply is connected to the pump which then commences to circulate water through the system, the supply voltage is also connected *via* the overheat thermostat contacts to energise the operating solenoids of

the main 60 ampere contactor and the thermostat control contactor. These contactors close and connect the 240 volt supply to the switching circuits of H1 - H6. The supply indicator lamp I_6 shows when the supply voltage is connected to the heating control circuits and another indicator I_7 shows the connection of the supply to the pump. S1 is the boost heat control switch which can be set to give 4 kW or 8 kW of heating, as required, to raise the temperature of the main tank to the selected point in the minimum of time. Similarly the thermostatically controlled heating can be set by S₂ to 1 kW, 2 kW or 4 kW of heating as required. Each separate heating circuit is protected by a fuse and has an indicator lamp $I_1 - I_4$ to show the circuit operating conditions.

As the temperature nears the selected operating point the boost heat circuit is switched off manually by S₁. If by error this is not carried out, the overheat thermostat will protect the system by switching off the main supply. On switching the boost heat circuit off, heat is then supplied solely by the thermostat controlled circuit. On reaching the correct temperature in the main tank, the con-

tacts in the toluene tube close thus energising the post office relay whose contacts open and de-energise the thermostat control contactor, the "off" indicator lamp I_3 lights simultaneously. According to the ambient temperature the thermostat control switch S_2 is set manually to obtain thermostat control circuit operation at intervals, the lower the heat input to obtain thermostat control, the better for precise control. If the heat input is too low the heater will be switched on almost permanently, if too high, the heater will be switched on at infrequent intervals, the ideal is when the thermostat is switching the heating circuits on and off fairly frequently.

Operation of Main Tank Heating Thermostat Circuit

The small step down transformer T1 supplies 24 volts to a half wave rectifier CV 7013, the resulting rectified direct current is connected to one contact of the main tank heating thermostat (toluene tube type), the contact of which is connected to a post office relay solenoid. On reaching the operating temperature the main heating thermostat contacts close and a d.c. voltage of approximately 30 volts is applied to the relay solenoid across which is connected, through the relay contacts, a 50 microfarad capacitor to prevent chattering. Connection of the rectifier to this capacitor through the post office relay contacts ensures a sparkless contact and a rapid rise of d.c. volts which closes the post office relay contacts sharply. When the temperature falls by approximately 0.1° Fahrenheit, the main tank thermostat contacts open and the d.c. voltage is removed and the solenoid of the post office relay is de-energised. There is no spark at either make or break of the thermostat contacts because of the capacitor C_1 . C_1 maintains the voltage across the relay solenoid on the opening of the thermostat contacts so that the voltage across these is very small at the instant of opening. Immediately the relay contacts open the capacitor C_1 is disconnected and the relay opens rapidly and cleanly. Another pair of contacts on the post office relay controls the solenoid of the 20A contactor which supplies the power to the thermostatically controlled heaters, when the supply is on the heater indicators I_3 and I_4 show the heating situation, when the supply is off the indicator I_5 is lit. Thus heating conditions may be assessed at a single glance.

Fault Conditions

In the event of failure in any part of the system the design is such that the system will "fail-safe".

Pump Failure

This is the most serious defect likely to occur but has not occurred in three or four years of operation. A test button S4 is fitted to simulate this condition in order to test the protective circuits at intervals. Should the pump fail to start, or its protective fuse blow and produce the same effect, the temperature in the small heating tank will rise. An over-heat thermostat fitted in the tank will open at 5° Fahrenheit or at any other desired setting above the main tank temperature setting and this will de-energise all the heater-circuits, the fault indication being given by the indicator lamp I_7 . When the temperature in the heating tank falls, the supply will be reconnected and the sequence will be repeated until the fault is corrected. The noise of the main contactor operating and the indicator lamp I_7 flashing is sufficient warning to the operator.

Overheating of Main Tank

Should the boost heat circuits be left switched on inadvertently after the initial heating of the tank, the only result is that the small heating tank temperature will exceed the required temperature by 5°F maximum and the supply will be switched off as in the preceding failure. This could only arise from operator negligence but attention would soon be drawn to the fault condition.

Cooling of Main Tank

Cooling of the main tank might be necessary under certain conditions of charge and discharge of the cells. A thermostat set to 0.5° Fahrenheit above the normal operating temperature, to prevent instability, may be used to operate an electrically operated valve to allow cooling water to pass through a heat exchanger fitted in the pump line. Alternatively a vortex tube cooling device may be substituted for cooling water and run from a supply of compressed air. Thus the tank environment may be as closely controlled under all conditions of use and ambient conditions as may be required.

APPLICATIONS AND CHARACTERISTICS OF SYNTHETIC RESINS

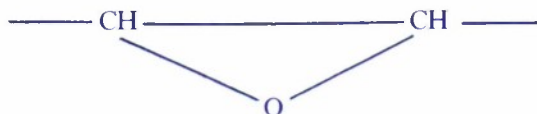
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Abstract

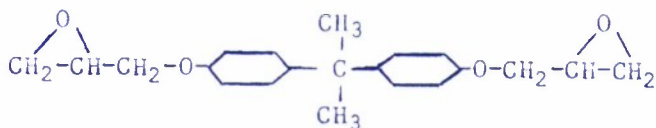
Synthetic resins are often used in underwater equipment. Typical applications are the filling of cavities, the joining of cables, the enclosure of electronic components and the termination of steel armoured cables. Some of the problems involved in manufacturing and using several synthetic resins are described and methods of overcoming them are recommended.

Introduction From a chemical point of view epoxy is defined as any organic mixtures characterized by molecules containing one or more ether rings of the following type:



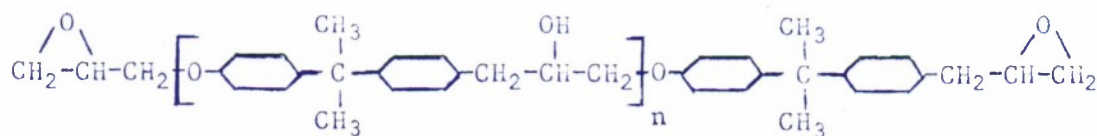
tant characteristic of epoxy resins. Thermo-setting is not restricted to epoxy resins and also occurs in polyester, phenolic and melamine resins. Because of the particular three-dimensional molecular structure they attain during setting, and the different methods of treatment, epoxies are superior to many other bonding materials in many respects, for example in their absence of volatile products, dimensional stability, resistance to solvents, chemical inertia, strength, resistance to thermic shocks, and high adhesive strength. The transformation into a three-dimensional solid polymetric structure is obtained by the action on the epoxy molecules of a treating agent (hardener, catalyst, and activator), which by breaking the epoxy rings causes the molecules to be activated and to gather into long chains.

The simplest epoxy resins derive from the combination of one molecule of biphenyl propane and bisphenol A with two molecules of epichlorhydrin:



With certain treatment these substances can lose their plasticity and become solid, a process known as thermosetting. This constitutes the most notable, and from the point of view of their practical use, the most impor-

Increasing the number of molecules of bisphenol A and epichlorhydrin in the reaction gives homologies of a higher molecule weight, with the following theoretical structure:



in which $n = 1, 2, 3, \dots$

It can be seen that, with the increase of the molecule weight, the hydroxyl group is also introduced into the molecule.

Generally no commercial resin consists of only one type of molecule, nor is it completely diepoxydic. Colateral reactions reduce the quantity of functional epoxy groups, so that in liquid resins there is an average of 1.9 epoxy groups per molecule, instead of the theoretical two. For solid products, with a higher molecule weight, the average content of epoxy groups is even lower.

All these products are thermoplastic and the subsequent action of the cross-linking catalyst creates thermohardener products. The hardening agent can take a direct part in the reaction, or can act simply as a catalyst; the resulting final structure will thus be a union of similar or dissimilar molecules (heteropolymer or homopolymer structure).

Treated epoxy resins, apart from the qualities mentioned above, are characterized by an excellent behaviour as dielectrics. The characteristics and uses vary with the type of resin, the hardening conditions, and the type of hardener, as well as with the nature of additive loading, flexibilizers, accelerators, etc. The field of application of this class of synthetic products is large. There are specific products for casting, enclosing, glueing, lining, impregnating, varnishing, laminating, moulding (in dies), modelling, etc. However, during the hardening process quite a number of phenomena can cause damage to the required casting, or bond; a mix can contain bubbles, holes, inhomogeneities, fractures, plasticity and other factors. These cannot always be disregarded, nor are they always easily eliminated.

This study begins by examining and physically defining some of these characteristics: there follows a discussion of the most common defects encountered in the practical application of epoxy, such as filling, covering, joining, casting. Finally an attempt is made to establish the most probable cause of these defects and hence some possible remedies. The study was based on the examination of such commercial products as Araldite, DER, Epikote (used pure or modified, as indicated).

TABLE 1.

Characteristics of Araldite D and Hardener HY 951

Mixing Proportion	Resin Hardener	100 8-10	
Physical State	Resin Hardener	Liquid Liquid	
Viscosity of the Mixture	20°	ca 1500	
Resin hardener (measured in centipoises)	60°	- -	
Characteristics	Standard	Unit	Value
Ultimate tensile strength	VSM 77101	kg/mm ²	5.5 - 8.0
Breaking load under compression	VSM 77102	kg/mm ²	9 - 10
Breaking load under bending	VSM 77103	kg/mm ²	8 - 11
Specific gravity	VSM 77109	g/cm ³	1.15 - 1.20
Coefficient of linear thermal expansion	VSM 77110	10 ⁻⁶ mm/mm°C	90 - 95
Young's modulus	VSM 77111	kg/mm ²	300 - 350
(Martens) Deformation	DIN 53458	°C	40 - 50
Thermal conductivity	DIN 51612	kcal/mm °C	0.18 - 0.22
Dielectric constant	20° 90°	VDE 0303	3.9 - 4.1
Loss Angle	20° 90°	VDE 0303	% 1.4 - 1.7 13 - 15
Electrical resistance	20°C	VDE 0303	10 ¹⁵ ohms/cm 2.5

When the brand is not mentioned, the discussion refers to the Araldite D-hardening HY-951 process, the main characteristics of which are shown in Table 1.

Characteristics of Epoxy Resins

There are two epoxy systems:

(a) Two separate components (resins and hardeners), which must be united and well mixed to ensure hardening.

(b) One component, the resin, to which a catalyzing agent, that is active at high temperatures has already been added; such a system requires only heat for hardening.

It is usual to separate system (a) into two groups according to whether the hardening occurs with or without heat. A resin that hardens only with heat when a certain type of hardener is used can harden at room temperature when a more reactive hardener is used. Hardening with heat uses hardeners with a basis of dioxides of organic acids (as phthalic, malic, succinic acid), often in the presence of a small percentage of catalyzers with a basis of triphenylmethane. Hardening without heat requires far more active organic bases, such as amines, starch and their derivatives. Clearly, the increased reaction of the hardening systems at room temperature shortens pot-life and increases the isothermicity of the reaction. In general, resins hardened at room temperature distort with heat and their mechanical properties change at a lower temperature than when the resins are hardened by heat. However, dioxide products create resins of notable resistance to humidity that have higher dielectric characteristics.

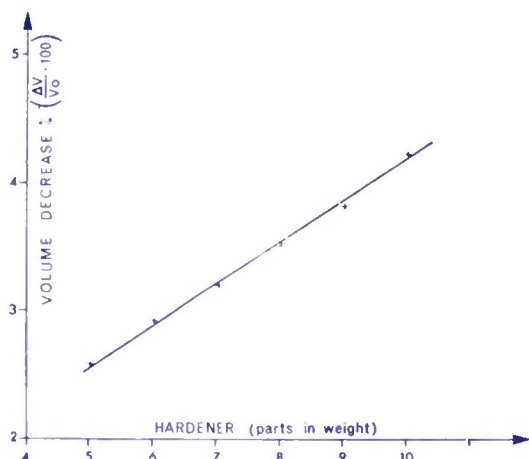


FIG. 1. Hardening velocity as a function of the treatment temperature

Speed of Reaction and Exothermicity

During the hardening of epoxy resin the reaction follows the general laws that regulate the procedure of all chemical reactions. Their characteristics are influenced in particular by the temperature and by the initial relationship of the reactors present in the mixture. The most apparent physical indication of the reaction is exothermicity (heat) and also the contraction of the system with respect to the initial dimensions.

The speed of hardening is found to double with approximately every 10°C increase in temperature.

For a compound of 100 parts in weight of resin and 10 of hardener, the average times for hardening as a function of temperature are as shown in Table 2.

TABLE 2.

Temperature (°C)	Average time for hardening (min)
15	1300
20	960
40	220
50	120
80	15 - 20
100	5

The reaction of the epoxy is exothermic. During the hardening, the temperature of the compound increases to a maximum, and then decreases. This is shown in Fig. 2 for systems with 8, 10 and 20 parts in weight of hardener to 100 parts of resin. It can be seen that the maximum temperature reached by the resin increases with the percentage of hardener whilst, conversely, the reaction time is reduced.

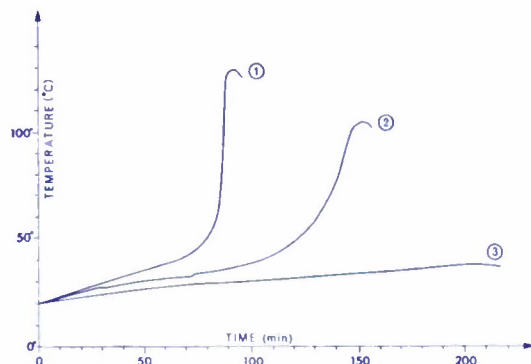


FIG. 2. Temperature profiles for the systems:
(1) 100 parts of resin/20 parts of hardener
(2) 100 parts of resin/10 parts of hardener
(3) 100 parts of resin/8 parts of hardener
100g of compound at an ambient temperature of 20°C.

The increase in temperature of the system is due to the increase in the quantity of heat generated per unit of time; the more groups that react during this lapse of time, the shorter is the total time available for dissipating the heat caused by the increase in reaction speed. The same phenomenon is observed when the temperature of treatment

is raised. For the same quantities of resin of the same composition, the total amount of the heat generated will remain the same, varying only with the operating temperature. As the temperature rises and as the speed of the reaction is increased, the heat is generated in a shorter time and its dissipation becomes more difficult.

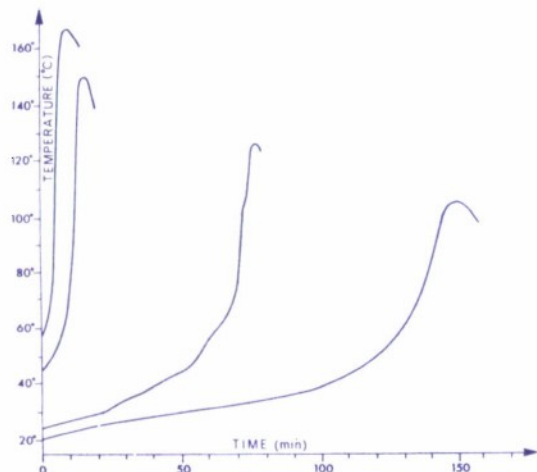


FIG. 3a. Temperature profiles as a function of the treatment temperature
Compound: 100 parts of resin
10 parts of hardener
Quantity: 100g

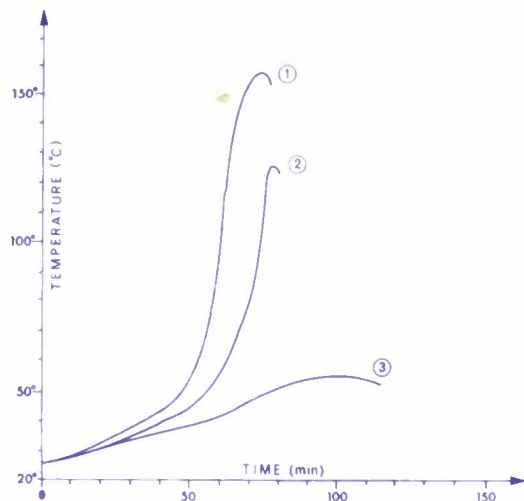


FIG. 3b. Temperature profiles as a function of the treatment mass
(1) 200g
(2) 100g
(3) 50g
Compound: 100 parts of resin
10 parts of hardener
Ambient Temperature 25°C

Fig. 3 shows the hardening curves of three systems of equal mass and composition (10 parts in weight of hardener to 100 parts of resin). The temperatures of treatment were 20°, 46° and 55° C. If all other conditions are equal, the quantities treated are increased, and the phenomenon of exothermicity can again exert its negative influence.

Heat dispersal is more difficult for the centre of the cast than it is for the external areas. Areas of different speeds of hardening are thus created, with different isothermicities generating convective currents, tensions, gas bubbles and cavities.

Fig. 3b shows a comparison between the hardening curves of three systems consisting of 200, 100 and 50 grams of resin. The relationship in weight between the epoxide and the hardener was 100 to 10 and the temperature was constant at 25° C.

Contraction

Contraction is another phenomenon that causes concern under certain operating conditions.

During the hardening process contraction of the treated mass takes place, causing cracks, breaks, roughness of texture, airholes, and internal tensions, that can sometimes damage the cast beyond repair.

Figs. 4 and 5 show the variation of volumetric contraction with changing percentages of hardener and treatment temperature, respectively, all the other conditions remaining constant. The experimental results confirm that, at least between the intervals examined, varying the quantity of hardener or the temperature of treatment, increases the contraction linearly.

The graph of Fig. 4 shows the results obtained when varying the percentage of hardener and maintaining a constant temperature of 20° C.

For quantities of hardener above 10 parts in weight per 100 parts of resin, the volumetric contraction does not obey the linear law, as is shown by the values obtained for compounds with 20 and 30 parts of hardener, 5% and 5.9% respectively. The graph of Fig. 5 shows that the contraction is a function of the temperature when either 6 or 10 parts in weight of hardener are used with 100 parts of resin.

Determination of the linear contraction, again for the same epoxy system, tested with 8 parts of hardener and at a temperature of

18°C gave the average percentage values shown in Table 3.

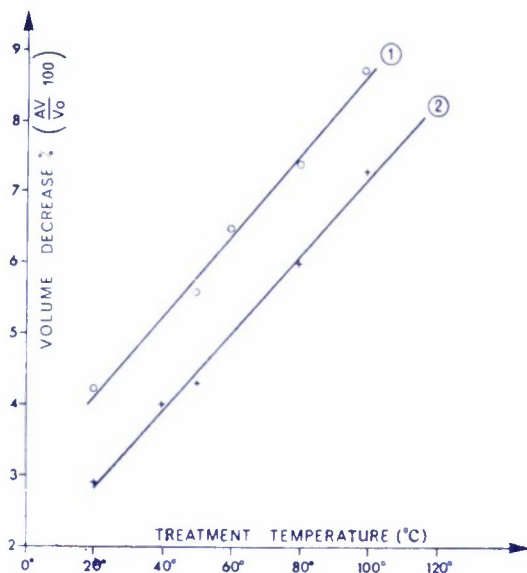


FIG. 4. Percentage volume decrease as a function of treatment temperature for the systems
(1) 100 parts of resin/10 parts of hardener
(2) 100 parts of resin/6 parts of hardener

TABLE 3.
Linear Contraction

Time	%
15 hours	2.5
21 hours	3.0
48 hours	3.1
96 hours	3.1

Viscosity

Viscosity is a very important characteristic of epoxy resins and it can be the prime factor in the choice of resin, for some applications.

The viscosity of a pure liquid resin, which is normally between 150 and 300 millipoise at room temperature, can be made to vary between vastly greater limits by simply adding a substance that dilutes or thickens the resin (See Fig. 6).

Using the right substance it is possible to give an epoxy resin thixotropic characteristics that allow it to be used as a varnish even on vertical surfaces.

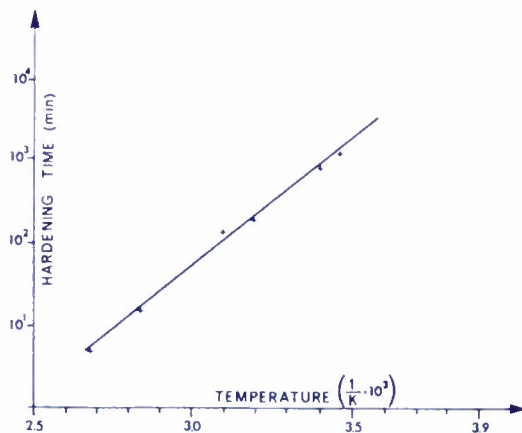


FIG. 5. Percentage volume decrease as a function of the quantity of the hardener
100g of compound
20°C ambient temperature

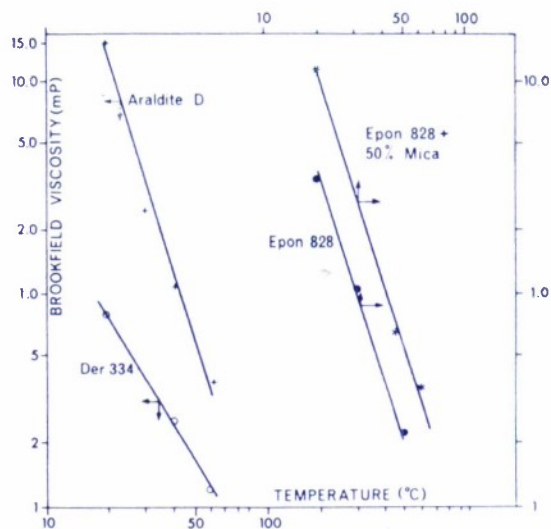


FIG. 6. Viscosity as a function of temperature

In fact, thixotropic fluids show a lessening in viscosity proportional to the increase in shear rate; so that during their application with a brush they flow easily, and then regain their viscosity.

Fig. 7 shows a graph of the viscosity as a function of the shear rate for an epoxy resin loaded with a thixotropic agent containing a silica colloidal base.

TABLE 4.

Samples (56 mm × 20 mm × 3 mm)	Days of immersion				% Variation of Weight
	2	5	10	15	
1. With 10 parts of HY951 hardener	0.14	0.28	0.32	0.33	
2. With 5 parts of ethylic alcohol	0.18	0.32	0.34	—	
3. With 5 parts of xylene	0.15	0.30	0.32	—	
4. Charged with microballoons of glass (diam. 10 - 100 μ m) at 20% weight of resin	1.2	1.7	2.18	2.28	
5. Charged with stainless steel powder at 100% weight of resin	0.10	0.18	0.23	0.25	
6. Charged with mica powder at 50% weight of resin	0.04	0.055	0.062	0.065	

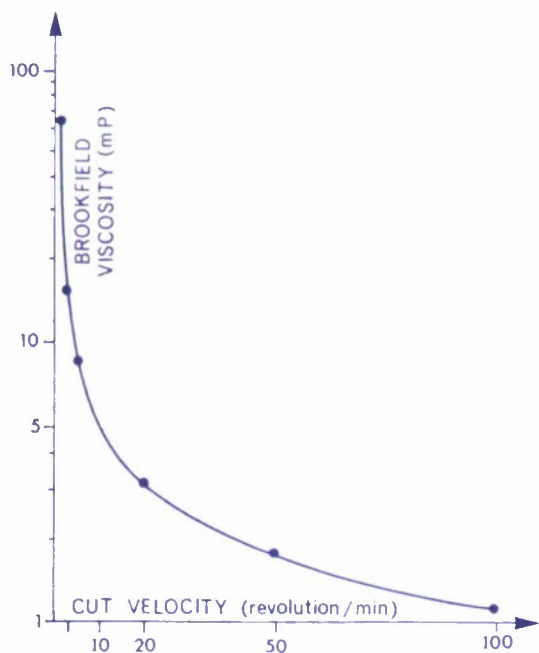


Fig. 7. Viscosity as a function of velocity for a thixotropic resin

Absorption in Water

Tests of absorption of distilled water at 20°C were made on six samples of Araldite D. The percentage increase in weight with time was as shown in Table 4.

These results show that maximum absorption occurs when the resin is charged with microballoons of glass. The addition of such diluents as alcohol and xylene has very little effect on the water absorbant properties whilst mica reduces it notably. A reduction is also noted with the addition of powdered metal.

Diluents for Epoxy Resins

The relatively high viscosity of epoxy resins, especially when they contain inert charges, can prevent their being used whenever a high level of penetration is required. To lessen the initial viscosity of the resin, the resin can either be pre-heated or diluted. However, there are limitations to the pre-heating of the resin because of the consequent increase in isothermicity and decrease in pot-life.

With the use of diluents it is essential to distinguish between reactive and non-reactive types. Reactive diluters are those that participate in the hardening reaction. They consist of monoepoxides, such as phenil-glyceride ether, causing a decrease in the average number of epoxy groups per molecule and a consequent decrease of the number of cross-links in the hardened resin. If added in quantities larger than 10-15%, they greatly reduce the mechanical properties, the resistance to heat, and the resistance to the solvents of the finished product.

Non-reactive diluents are those that do not participate in the hardening process. They have generally a high volatility, so that only a small portion remains in suspension in the hardened resin. Toluol, xylol, and acetone are the most current examples. Dibutyl-phthalate is also a non-reactive diluent that is used as a plastifier and can increase the adhesive properties of the resin; however, it tends to sweat and also brings about a loss of resistance, especially when more than 10% is added.

Alcohols, it should be noted, whilst possessing better solvent qualities than epoxy resins, are good hardening accelerators. The action of alcoholic OH hydroxyl on the molecules helps to break up the epoxidic rings and their ensuring reaction, the alcoholic molecule remaining intact at the end of the process. The hardening curve shown in Fig. 8 confirms this catalytic action of ethylic alcohol. They refer to mixtures with 10 and 8 parts of hardener, diluted respectively with 3 and 5 parts of ethylic alcohol, under the same conditions of treatment as for those shown in Fig. 2.

Compared with mixtures without diluents, an increase of 11°C and 18°C in the isothermic peaks is noted, associated with an average reduction of 50 minutes in the time required to reach these maxima.

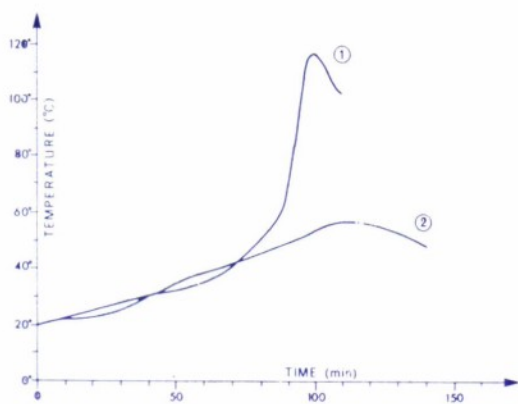


FIG. 8. Influence of diluents on the hardening process

- (1) 100 parts of resin
10 parts of hardener
3 parts of alcohol
 - (2) 100 parts of resin
8 parts of hardener
5 parts of alcohol
- 100g of compound
20°C ambient temperature

TABLE 5.

(Temperature 20°C)

Sample No.	Hardness (Shore D) Days			
	1	10	16	30
1	50	65	65	—
2	25	52	60	61
3	54	58	62	62
4	35	68	70	70
5	55	60	64	64

Usually, in systems with diluents, the hardening process takes more time, as is shown by the values of hardness in Table 5, taken from some samples as for Table 4.

Adhesion

Because the molecules of epoxy resins contain groups with a high polarity, they have excellent adhesive properties in relation to many materials.

A low-contraction hardening produces an adhesion layer in which the bond is stronger.

Epoxy resins can be mixed in such a manner as to obtain the properties of viscosity, wetness, and penetration as applied to widely different needs without impairing their adhesive qualities. Essentially, the adhesive properties are due to two factors: adhesion to the adherent and mass cohesion.

The excellent adhesive properties of epoxidic products have already been mentioned; their cohesion, with an adequate hardening cycle, can reach such a value that the break-up under force occurs rather in the materials bonded together than in the resin (*e.g.* the adhesion of glass to aluminium).

The mechanical properties of a bond are basically influenced by the following factors:

- (a) Nature of the materials to be bonded.
- (b) Condition of the surfaces.
- (c) Formulation of the resin.
- (d) Condition of hardening.
- (e) Operating temperature.

The thickness of the film of resin applied between the adherents should be between 0.1 mm and 1 mm. Thinner layers can cause uneven spreading of the resin, so that some parts are not wetted enough and there is an irregular distribution of the forces under tension.

Before application of the adhesive, the surfaces must be thoroughly cleaned to remove grease and other foreign matter that could come between the adhesive and the adherent. In addition, mechanical or chemical treatment can be used, *i.e.* etching or sand blasting, in order to increase the surface adhesion.

The adhesive properties of an epoxide can be improved by adding the right quantities of inert loading such as fibres of asbestos, aluminium, mica, silicon, aluminium powder, and ferrous oxide, such fillers make the shear resistance two or three times greater than pure resin.

Table 6 compares the values of the shear resistance of steel plates bonded with Epikote 828 resin, treated with various amminic hardeners, some pure and others with inert charges.

TABLE 6.

Conditions of test:

Temperature: 20°C - 80°C; overlap: 12.5 mm.

Size of the samples: 1.2 × 25.4 × 100 mm

Charge	Quantity % of weight of resin	Shearing Resistance	
		20°C	80°C
Pure resin	—	175	85
Aluminium	100	120	180
	30	200	130
Silicon dioxide	50	180	110
	20	240	155
Ferric oxide	100	210	200
	50	200	190
Mica	100	220	110
	*130	260	160

*Hardener: diciandiamide.

Hardening: 1 hour at 160°C.

Defects in Casting

Some of the more important and common defects encountered in using epoxy resins are:

1. Formation of bubbles and holes.
2. Separation of liquid parts and formation of superficial drops.
3. Resin remaining soft and tacky.
4. Cracks, flaws, roughness.
5. Burns.

Tests to establish the origin of these defects have enabled the causes to be identified and the best method of avoiding them. The success of an epoxy resin depends largely on attention to these details in application.

Formation of Bubbles and Holes

At the end of the hardening process the epoxy resin may have bubbles of air and cavities on the surface, or within the volume. Possible causes for these are:

- (a) Air absorbed by the resin, either during the mixing, or, prior to mixing.
- (b) Adhesion of air to the walls of the containers.
- (c) Impurities.

This air cannot always be exhausted from the cast before solidification and is therefore trapped in the solid mass. This can be prevented by vacuum casting, sub-division of the cast into several parts, increase of the treatment temperature, and thorough cleaning of all the parts coming into contact with the resin.

Attention should be paid to (1) the shape of the objects, to avoid forming stagnation points for the gas, (2) the material from which the parts are made, and (3) wetness characteristics, bringing about the formation of more or less persistent foam at the points of contact.

Apart from air bubbles, the cast can also contain gas bubbles due to the evaporation or decomposition of the solvent when too high a temperature is reached or when the object is left for too long in vacuum.

The parameters already examined can influence the speed of reaction. Too fast a reaction causes high isothermicity, thus large contraction and consequent internal tensions.

Apart from possible breaks, cavities can form which the resin fails to fill because of the rapid increase of viscosity; in addition, high temperatures facilitate decomposition of the product, resulting in the production of gas and gas bubbles.

Before the reaction commences, viscosity depends only on the characteristics of the resin and diminishes with the increase in temperature.

To make mixing easier, especially when the use of a low viscosity product is desired, one can increase the fluidity of the mixture by slightly heating the resins, keeping the temperature between 30°C and 40°C. For loaded

resins however, the heating can be up to 70°C, according to the reactivity of the hardener used.

The components can be heated either separately, or after blending. It should, however, be remembered that this practice can cause problems once a high exotherm is reached.

To lessen the viscosity of the system one can still resort to diluents, but it is first advisable to evaluate the advantages and disadvantages of this.

Formation of Superficial Drops

At the end of the hardening process, the surface of the cast might be covered with drops of liquid. These consist generally of hardeners, diluents or plasticizers that have separated from the resin during the hardening process.

There are several possible causes for the separation:

(a) Inadequate mixing of the components or too short a hardening period cause separation because the specific weight of the substance becomes less than that of the resin.

At the limit, too little mixing can lead to superficial stratification in which only the lower layer of the resin completes the hardening cycle. The right consistency of the mixture can be judged by the homogenous colour assumed by the resin throughout.

(b) Air-bubbles and Impurities.

These have an influence, probably explained by the fact that their upward movement operates a suction on the hardeners, particularly when separation is made easier because of incompleting amalgamation.

Maintaining a slightly higher treatment temperature lessens the hardening time, makes the expulsion of air easier, and reduces the dangers of dust pollution.

(c) Incompatibility of the Components.

Imperfect compatibility between resin and other components can bring about incomplete reaction and their final separation. This has not been studied in detail, but it has been observed when using diluents, that above a certain percentage, and at the end of the hardening, there is a sweating effect. The quantity of substance separated was proportional to the excess of the diluent.

Soft and Tacky Resin

This defect can also have several other causes. They are partially the same as those

examined before: *i.e.* not enough mixing, too low a temperature, and a wrong relationship between different components of the mixture.

Here, however, the contamination by foreign substances assumes a greater importance since it can delay, or prevent the hardening process. The most obvious examples are with impurities such as oils or hydrochloric and sulphuric acids.

Superficial tackiness occurs especially where resin is applied thinly with a slow hardening process; isothermicity is caused by the ambient humidity due to the hygroscopic properties of some hardeners (in general those with a base of amino-aliphatics) in suspension within the resin. At the interface a ternary system is created of resin-hardener-water, in which the various components are in equilibrium, and prevent the hardening process.

Cracks, Flaws, Roughness

The resinous mass may have flaws and cracks. Generally this can be attributed to too high a temperature being reached locally by the resin.

The cracks and the flaws begin to form in the central part of the cast, where the dissipation of heat is more difficult, rather than in the external areas.

The cause of too high a temperature and the remedies have been examined, noting again that the excess heat can be removed by use of refrigeration, air or water for example.

When the quantity of resin cast is large, it is better to operate by successive castings, proceeding with a new cast only when the previous one has almost completed its hardening cycle; this makes the bonding of the resin easier. Again, the main cause of superficial cracks can be high temperature, causing important internal tensions. However, it has been noted that these disappear once the phase of hardening or gelification has started.

Burns

The colour of solidified resin is normally tinged with yellow. However, when temperature increases, a brown colour appears (the intensity of which depends on the limit of temperature reached), and this colour propagates outwards from the centre of the mass.

Acknowledgements

The authors are indebted to the Commissione Permanente della Marina Italiana for their assistance in the mechanical tests and to Mrs. Jane Pietropoli for her translation into English.

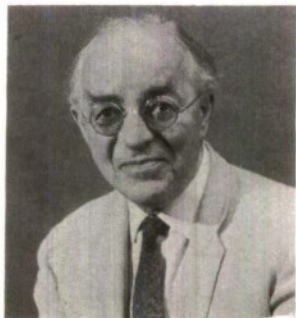
NOTES AND NEWS

Admiralty Materials Laboratory

A meeting of the Basic Science Section of the British Ceramic Society on "Ceramics for Turbines and other High Temperature Applications" at Cambridge on 4-6 July 1972 was organised by Dr. D. J. Godfrey of the Admiralty Materials Laboratory. Of the 28 papers presented, no less than 21 were presented which were wholly or partly devoted to silicon nitride. The meeting attracted the largest attendance for many years at a Basic Science Section Conference, and more than a quarter of the participants came from abroad. (See *Nature* Vol. 238, July 21, 1972).

Dr. R. H. Warren left AML to take up his appointment as Materials Officer on the staff of DDS Washington.

Dr. H. G. Stubbings, Principal Scientific Officer, retired from the Royal Naval Scientific Service on 20 September 1972, after 28½ years as a marine biologist in Admiralty service.



His early formal education was at Cambridge University where he was an Exhibitioner and later a scholar at St. Catherine's College, and was awarded an honours degree in Zoology in 1934. In the same year he was also successful in gaining a B.Sc (External) in Zoology from London University.

Research on the biology of the "soils" of the sea floor, plus an introduction to the barnacles, led to the award of a Ph.D. degree from Cambridge, and, incidentally, shaped his future zoological career.

His appointment to Professor (now Sir) A. C. Hardy's plankton survey team at University College, Hull, unfortunately coincided with the outbreak of war, and he turned his attentions to the investigation of pests of stored food-stuffs. This terminated in 1944 when he was transferred to Admiralty service as a TEO III at Central Metallurgical Laboratory, Emsworth, to work on biological aspects of ship fouling and its prevention. He accepted the offer to continue this work after the war.

Following the closure of CML in 1956 he was transferred to AML where he enhanced his reputation as an international authority on barnacles, which was recognised by London University in the award of a D.Sc. degree.

Two spells of overseas duty in Nigeria and Southern India widened even further his knowledge of barnacles and allowed him to indulge in an interest in plants, both living and dried. Some of the former, are still flourishing under Dr. Stubbings' care after 14 years, the latter repose in the presses of the Royal Botanical Garden, Kew.

In recent years he has spent much of his time investigating the drag-reducing properties of plant polysaccharides and his retirement will enable him to renew his work on barnacles. He has also been asked to make an investigation of the mud-fauna of Poole Harbour on behalf of the Nature Conservancy.

Dr. Stubbings, in addition to his professional duties, has helped to stimulate a keen interest in the flora and fauna present within the confines of AML and in the surrounding Dorset countryside, which will be gratefully remembered by many of his colleagues.

Mr. J. J. Brunt joined Admiralty Service at Bragg Laboratory Sheffield as a TEA III on 11 July 1938 and was promoted to TEA I on 1 April 1942. On reconstruction he was made an Established EO on 1 January 1946.

During his first period at Bragg Laboratory, Mr. Brunt was concerned initially with chemical analysis of materials/weapons especially metals and rubbers. He later worked on the Metallurgy side.

On 1 July 1948 he transferred to AML to initiate work on the applications of electron microscopy to metallurgical problems. Electron microscopy was then in its early days and Mr. Brunt not only developed methods of applying this powerful technique to metals and metal components but extended it to polymer components particularly with regard to fillers and their distribution. For this work he was promoted to SEO on 1 July 1951.

He then transferred to the Rubber and Plastics Division at AML and brought his knowledge of methods of characterisation and evaluation of materials to the Rubber and Plastics field.

On 22 August 1961 he was promoted to CXO and transferred back to Bragg Laboratory to take charge of all the chemical analysis at that laboratory and to act as Deputy to Superintending Scientist bearing a major part of the burden of the day to day running of the laboratory.

On the closure of Bragg Laboratory he returned to AML on 6 June 1968 with a small expert team to develop rapid methods of analyses of inorganic materials, and in October 1970 became Head of Chemical Services organising a most successful section to provide a service to MOD R & D establishments, Fleet and Naval Bases and MOD Design Depts. This has proved very successful and is held in high repute by the many "customers" both for the quality of the results, the rapid answers to urgent problems and the sound advice given.

Mr. Brunt retired on 7 August 1972 after 34 years of loyal service to the Navy being always willing to turn his very considerable expertise to any type of problem that required solution.

He was presented with an electric toaster and electric mixer by Dr. R. G. H. Watson, Director AML on behalf of his colleagues at AML, CDL DR Mat 1 and Bragg Laboratory. Mr. and Mrs. Brunt were entertained to dinner at the Dormy Hotel, Ferndown by some of his colleagues on 10 August 1972.

Admiralty Surface Weapons Establishment

Mr. N. A. Walter recently attended the NATO Reliability Testing and Reliability Evaluation Conference held at The Hague during the first week of September. This second NATO conference on the subject attracted wide interest, and Mr. Walter is to be congratulated that his paper on the "Accelerated Life-Testing of Thick-Film Resistors" was accepted by the Operational Research Panel which selected the papers to be read. The statistical papers presented included those discussing confidence bounds for system reliability, a survey of theoretical repair policies, various distributions and the problem of applying theory in the absence of sufficient relevant data. The practical papers presented included those covering the difficulties of following reliability plans, the use of accelerated test systems to forecast failure modes and mechanisms, the problems of demonstrating reliability growth and achieved reliability, and discussions on methods of data collection in the field. The conference emphasised the wide gap which still exists between the statistical approach to reliability problems and their practical application.

Mr. F. C. T. (Fred) Short retired on Friday, 6 October, 1972, having completed 44 years in the government service. His career began in 1928 at Portsmouth Dockyard, where he served an apprenticeship in the Electrical Engineering Department. He subsequently followed his trade for two years and then, in 1935, joined H.M. Signal School. A further year later, he joined the Torpedoes and Mining Department in London. A year later he set out on an entirely new career with the Inland Revenue Department but was recalled to Admiralty service with the outbreak of the Second World War.

He was promoted to Leading Draughtsman in 1949 and to Senior Draughtsman two years later. For most of his time in ASRE/ASWE, he was concerned with engineering design having been employed on Radar Types 984 and 901 and the Comprehensive Display System (CDS). More recently, he has been concerned with submarine communications.

In accordance with his wishes, there was no public presentation of his retirement gift. However, a book of quotations and a cheque was presented to him privately by Mr. F. L. Dore, the Drawing Office Manager, on behalf of his friends and colleagues who wish him and his charming wife a happy and useful retirement.

Admiralty Underwater Weapons Establishment

AUWE was shocked to learn of the death on 17 September of **Roy Scholey**.

Although he was a member of that select body, the holders of the A Met from Sheffield University, he spend his early career in the Chemical Laboratory of the English Steel Corporation. Here he had his first introduction to shock and vibration problems, and protected a chemical balance from passing steelworks trains by suspending it with cords from the ceiling. After a period of National Service in the Royal Air Force he returned to English Steel and set up the Micro Chemical Laboratory. His success was noticed by other Laboratories and in 1954 he joined the Bragg Laboratory as an Experimental Officer, doing similar work.



For the next ten years he continued as an Analyst at Bragg. He developed a number of new analytical methods and became, *en passant*, an authority on the analysis and examination of precious metal electroplates.

In 1956 he was promoted to Senior Experimental Officer and on the integration of the Naval and Army Chemical Inspectorates he remained with the Navy and transferred to the Naval Ordnance Inspection Metallurgical Unit. Here he was involved in sorting out problems of the Inspectorate—often why things cracked or bent or were otherwise unacceptable.

This brought him into contact with AUWE and in 1969 he joined the Materials Division at Portland. Here his cheerful banter soon became familiar.

He took over the Corrosion Section and quickly became known as a solver of problems, both in the Laboratory and in Committee.

He applied his administrative talents also to the social life of the Establishments in which he had served and recently had smoothed the way for a record number of guests of the AUWE Annual Summer Cocktail Party.

At Portland the work he started will be continued and his successes will be his memorial.

We extend our sympathy to his wife and children as they re-adjust to life, now back in the Sheffield area.



The Assessment Division at AUWE have been placing increased emphasis on studies of the performance of equipment currently in Fleet use and from this aspect and the equally important one of ensuring that forward looking studies are realistically based the opportunity was sought to participate in the major Fleet exercise WESTHOE. AUWE observers were given billets in seven of the ships involved as well as being represented at the MHQ. The observers found the participation invaluable and it is to be hoped that in due course the Fleet will itself benefit.

Mr. R. W. Willmer, DCSO, who since December 1968 has held the post of Head of Weapons Department, left in September to assume a new appointment in GCHQ Cheltenham.

Captain K. Lobb, R.N., has assumed the appointment of Manager Air Systems in the new Underwater Weapons Projects Directorate.

The Electronics Research Council visited AUWE(N) on 16 June. After a short business meeting of the council a number of presentations were given by members of the Sonar department covering areas of particular interest to the council.

Dr. J. E. Wood has been appointed to the post of Head of Sonar Department in AUWE as DCSO. His responsibilities will include research programmes for sonar and fire control and the provision of support, including facilities, for projects within Director Underwater Weapon Projects' programme.

Dr. Wood has had a wide experience of research within AUWE including the physics of magnetism and acoustics for mine counter-measures, weapons and sonar systems. In recent years he has been head of a division within the Sonar Department concerned with research on ship noise reduction and sonar propagation phenomena.

Mr. S. D. Mason has been appointed to the post of Manager Surface Ship Systems, at DCSO level, in the Directorate of Underwater Weapons Projects. He will be responsible for all new weapon systems for use on surface ships, and in addition post design and repeat production of underwater weapons. For a number of years Mr. Mason has worked in the Sonar Department of AUWE and since 1968 has led a division concerned with R & D of new sonar systems. He served as an exchange scientist at the Naval Undersea Center, San Diego, California from 1965 to 1967, and more recently has been project officer for a US/UK collaboration programme.

Mr. R. J. C. Bown has been seconded to take up a post in October as an exchange scientist at the Naval Undersea Center, San Diego. At AUWE he has been actively involved in joint US/UK collaboration programmes.

After several years at AUWE, recently working with corrosion-resistant high-strength aluminium alloys, Dr. A. Thorpe, SSO, transferred to AML on 2 October. On the same date the Fuel Cell team, its mission completed, transferred from AML to AUWE in the shape of Mr. J. McFadyen. He will return to the Materials Division, being concerned with chemical aspects of materials for underwater weapons.

Naval Construction Research Establishment

Mr. S. B. Kendrick, O.B.E., has been awarded a special merit promotion to Deputy Chief Scientific Officer, for outstanding individual work in the field of structural design. The promotion will allow the officer to continue with his individual work, without the administrative responsibility normally associated with the grade of DCSO.

Mr. Kendrick is a leading authority on the structural design problems of ships and submarines. In particular he has made outstand-



ing contributions to the methods of designing submarine pressure hulls. As a result mainly of his efforts, pressure hull design has been put on a scientifically sound basis and the resulting design methods enable designs of adequate strength to be produced with the minimum weight penalty, and with minimal stress concentrations. In his current work he is advancing the use of finite element analysis techniques in the design and analysis of the structure of surface ships.



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Personal items are shown in *italics*.

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NOTICE TO READERS

The Editor extends to all readers of the Journal and particularly those of the younger generation, a cordial invitation to contribute articles of R.N.S.S., naval or general scientific and technical interest.

Authors are requested particularly to note that as the Journal is in the Restricted category the printing of material within its pages does not constitute open publication and does not prejudice the subsequent use of the material in the Journal of a learned society or institution, or in the scientific and technical press.

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